ASSESSMENT OF A RECREATIONAL FISHERY IN NORTHEASTERN MEXICO

A Thesis

by

ARTURO JOSE VALE III

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2009

Major Subject: Wildlife and Fisheries Sciences

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Approved by:

Chair of Committee,	Frances P. Gelwick
Committee Members,	William Grant
	Carlos Gonzalez
Head of Department,	Thomas Lacher

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ABSTRACT

Assessment of a Recreational Fishery in Northeastern Mexico.

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Arturo Jose Vale III, B.S., Texas A&M University

Chair of Advisory Committee: Dr. Frances P. Gelwick

The Northeastern region of Mexico has developed rapidly over the last few decades and reservoir construction has accompanied the growth of the region. As a result, recreational and sport fishing have become very popular. To regulate tournaments and to address growing exploitation concerns the Northeastern state of Nuevo Leon has begun to manage selected freshwater fisheries. Intensive management of warm water recreational species, however, does not have a long history in the region.

This assessment was designed to evaluate the population structure and feeding habits of largemouth bass and channel catfish at a small rural fishery in Northeastern Mexico to get insight into mortality, growth, reproduction, and length related feeding patterns.

Largemouth bass and channel catfish at La Juventud experience high mortality rates more than likely due to the selective removal of larger-older fish by angling. Extended spawning efforts at lower latitudes have also been implicated in accelerating the mortality of reproductively mature largemouth bass; however, studies regarding the onset, frequency, and duration of largemouth bass spawning in Northeastern Mexico are

necessary to determine spawning seasonality and the adverse effects that extended reproduction efforts may have on growth potential.

Largemouth bass grow fast during the first year of life and attain large sizes by age 1. Growth of young-of-year may benefit from an early onset of spawning and a long first-growing season, an abundant multi-species forage base of small fish, and frequent utilization of fish. Growth to age 3 and quality size (300 - 380-mm TL) is similar to that of populations from the Southeastern U.S.; however, the growth potential of individuals older than age 3 appeared limited by suitable sizes of prey. Channel catfish mean length-at-age values were similar to the mean of means for length-at-age-3 values of fish in Texas, and larger than the mean values from several regions in the Southern U.S.A.

Largemouth bass at La Juventud may spawn early in the year (early spring or earlier than spring) and late in the year (fall). Spawning success; however, may be adversely affected by fluctuating water levels associated with an arid climate and undesirable interactions with other nest spawning species.

Day-time gill net collections in 2006 and 2007 may have under sampled channel catfish. Gill net catches were low and variable; thus, interpretation of length, age, and weight data were constrained by small sample size.

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This research would not have been possible without our colleagues from the University Autonoma de Nuevo Leon. Dr. Juan Antonio-Vidalez, Dr. Karim Acuna-Askar, Sergio Rodriguez, Jesus Lozano, Rodolfo Garcia, Carlos Hernandez, Carlos Elozondo, Ringo Benavides, and Francisco Ortiz-Esquivar acted as a voluntary field crew, handled trip logistics in Mexico, and allowed me to use their laboratory facilities to collect biological data from fish specimens. Their expertise on the local flora, fauna, and geography improved the content of this work greatly.

Dr. Manuel Pina and Dr. Gary Wingenbach deserve acknowledgement for letting me tag along on a field trip throughout south Texas and Mexico. I was able to incorporate into this thesis much of what I learned during this trip about resource use in Northeastern Mexico into this thesis.

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Mark Webb, Jeff Henson, William Johnson, Mike Gore, and Joe Moczygemba at the Texas Parks and Wildlife Department office in Bryan provided me with the resources and direction needed to turn a 14-ft aluminum boat into the electrofishing boat used to collect a large majority of the field data for my research.

Last, but not least, I would also like to acknowledge my mother, father, brother, family, and friends for their unconditional love and support.

TABLE OF CONTENTS

LIST OF FIGURES

FIGURE Page

LIST OF TABLES

CHAPTER I

INTRODUCTION

In order to contend with the rapid population growth experienced within the last few decades, the Mexican government has built numerous dams throughout the country to provide domestic, agricultural, and industrial water supplies to burgeoning metropolitan areas (Lyons et al. 1998). The construction of reservoirs; however, can provide thousands to millions of hectares of impoundment for recreational and commercial fishing (Nielsen 1999) and the establishment of aquaculture and recreational fishing tourism is well documented at El Cuchillo, La Boca, Marte-R. Gomez, and Falcon reservoirs in Northeastern Mexico (Morales and Martinez 2006a; Morales and Martinez 2006b; El Norte 2008). Furthermore, the increasing popularity of largemouth bass tournament fishing in Northern Mexico has recently culminated in the establishment of a multi-state Mexican pro-angler tour in 2007 (El Norte 2008).

Fishery development has outpaced the knowledge generated about fishery systems in Latin American countries such as Mexico (Salas et al. 2007), and with the exception of a few large inland lakes and reservoirs that support subsistence and artisanal fisheries, the federal government has not traditionally regulated inland fishing as a major human activity (Lamb and Lybecker 1999). In the Yucatan peninsula of

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This thesis follows the style of the North American Journal of Fisheries Management.

southern Mexico, inland fisheries are not recognized by the government as among the primary human activities, and hence there are no data collected regarding the annual catches, the species caught, the resource users, nor the frequency and the seasonality of activity (Arce-Ibarra and Charles 2008). Freshwater fisheries in West-central Mexico face similar challenges (Lyons et al. 1998; Orbe-Mendoza et al. 2002) and although several freshwater fisheries in the Northeastern state of Nuevo Leon are now managed by Parques Y Vida Silvestre De Nuevo Leon, the intensive management of warm water recreational species does not have a long history in this region and information is limited. Management is even further complicated by the state of freshwater systems in Mexico which are severely threatened by the loss of water quantity, degradation of water quality, and invasion of exotic species as a result of rapid development and growth (Contreras-Balderas et al. 2003; Contreras-Balderas and Escalante-C 1984; Lyons et al. 1998).

Fisheries assessment is fundamental as a precursor to formulating fishery management plans (Peterman 2004; Salas et al. 2007); however, a shortage of consistent fisheries information, a limited amount of trained personnel, a lack of financial support for gathering information independently of landings, a lack of well-defined programs to evaluate resources on a permanent basis, and a lack of compliance as a result of the latter generates challenges to the assessment of fisheries in Mexico (Lyons et al. 1998; Salas et al. 2007). This assessment was designed to quantitatively evaluate the population dynamics and fish assemblage structure at La Juventud, a small rural impoundment in Northeastern Mexico. Of primary concern were population size and age structures, recruitment, growth, mortality, condition, food habits and an evaluation of regulatory length limits of recreationally desirable species largemouth bass and channel catfish. Secondarily, an analysis of the fish assemblage structure was conducted to describe interspecific and biotic-abiotic relationships. Aside from providing reservoir managers with information crucial for management, this study also describes and comments on fisheries science techniques and ecological and biological characteristics of recreationally desirable species in an environment outside the bounds of traditional U.S. inland fisheries studies where the components (biological, social, political, and economic) that shape fishery exploitation and the subsequent ichthyofaunal responses may differ. This assessment also provides an opportunity to evaluate population rate functions of one of the most sought after recreational species, largemouth bass, near the southern limit of its natural range (Contreras-Balderas and Escalante-C 1984; Miller et al. 2005).

The objectives relative to the assessment of population dynamics of the recreational fishery at La Juventud are to (1) evaluate population structures with respect to length and age data (2) evaluate the physiological well being of major sportfish species using condition indices (3) assess recruitment using seine hauls and the relationship between number-at-age and age (4) evaluate growth using mean length-at-age and von Bertalanffy growth models (5) analyze mortality using a linear regression of the natural log of frequency against age (6) assess regulations designed to maintain the quality of fishing (7) evaluate food habits of desirable sportfish species, and (8) describe the fish assemblage structure.

CHAPTER II

POPULATION STRUCTURE, GROWTH, MORTALITY, AND RECRUITMENT

INTRODUCTION

Recruitment, growth, and mortality are generally considered to be among the most important factors affecting the population dynamics of fish. Collection of largemouth bass and channel catfish length, age, and weight data will allow population structure to be interpreted, population rate functions (growth, recruitment, and mortality) to be quantified, and yield and harvest to be simulated across hypothetical minimum length limits for this sub-tropical region of Northeastern Mexico where information regarding the population dynamics of these recreationally targeted species is limited.

METHODS

Study Site

La Juventud reservoir is a 20 ha impoundment, established in 1986 on the upper Salinas River in west-central Nuevo Leon, Mexico. It is approximately 35 km northeast of metropolitan Monterrey in the Pesqueria sub-basin of the San Juan River drainage system (Figures 1 and 2). The region has an arid subtropical climate with a mean annual temperature of 22°C and mean annual lows and highs of 17°C and 28°C (; Coordinacion General de los Servicios Nacionales de Estadistica 1981). A system of intermittent and ephemeral streams that originate within Los Picachos Mountains account for the majority of reservoir inflows (personal communication, Sergio Rodriguez, UANL

Biologist) and stream discharge rates coincide with a highly variable bimodal precipitation regime, within which the first peak occurs in May-June and the second peak occurs in September-October during the tropical storm season (Flores and Navar 2002; Miller 2005). Long-term (1935-1996) mean annual precipitation ranges from 250 to 1300 mm/yr (Coordinacion General de los Servicios Nacionales de Estadistica 1981; Flores and Navar 2002; Miller 2005) and reservoir water levels have the potential to fluctuate drastically in such arid climate conditions.

La Juventud has a simple morphometry growing in width from four shallow tree-lined creeks and a series of shallow coves at its northern and eastern ends, into a deep open-water basin near the dam at its southern end. In 1997, mean depth at La Juventud was calculated as 2.9 meters with a range of 0.6-6.0 meters (Zarate 1997). La Juventud captures water from 352 hectares of agricultural watershed, and receives effluent from wastewater holding ponds that serve the nearby municipality of Marín; runoff also comes from land used primarily for sorghum and maize crops, and small confined animal feed operations (swine, cattle and poultry). One such operation is located approximately two kilometers upstream of the main tributary entering the eastern section of the reservoir.

La Juventud is owned by the Universidad Autonoma de Nuevo Leon (UANL) and managed by the faculty at the affiliated campus for the School of Agriculture (Facultad de Agronomia UANL), near Marín. Prior to 1998 water clarity at La Juventud was > 1-m Secchi depth. Such penetrating light conditions allowed infestations of the

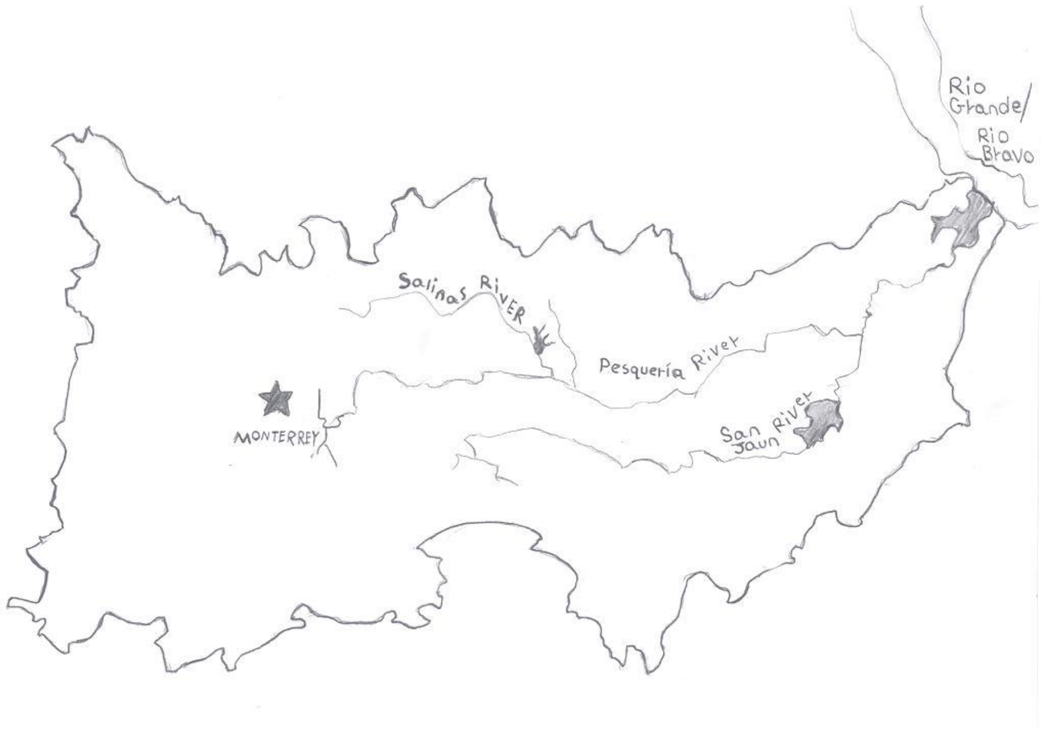

Figure 1. San Juan River watershed Nuevo Leon, Mexico.

Figure 2. Aerial photograph of La Juventud Reservoir.

submerged macrophyte *Hydrilla verticillata*, which colonized in dense mats throughout much of the littoral zone (personal communication, Sergio Rodriguez, UANL Biologist). A fertilization program, implemented in 1998, was designed to increase primary productivity of planktonic and surface algae, thereby reducing penetration of light needed for macrophyte growth. The program was discontinued after 2001, having achieved a significant reduction of macrophyte growth and a stabilized Secchi depth of 0.46 m. Based on Secchi disc transparency, and following the trophic index proposed by Chapra and Dobson (1981) and Forsberg and Ryding (1980), La Juventud is eutrophic.

La Juventud has multiple demands on its reservoir resources, which can have conflicting functions and goals. These include an inland recreational fishery, a water storage facility, and as an occasional venue for research ventures such as tilapia and carp aquaculture. Within the lower San Juan basin, the growth of metropolitan Monterrey and nearby populations threatens the integrity of water resources via pollution, as well as extraction for domestic use.

Ecologically, the ichthyofaunal assemblage in La Juventud is a mixture of indigenous species present before impoundment and species that have been either intentionally or inadvertently introduced. Initially, La Juventud was stocked with largemouth bass *Micropterus salmoides*, channel catfish *Ictalurus punctatus*, bluegill *Lepomis macrochirus*, and threadfin shad *Dorosoma petenense*, then common carp *Cyprinus carpio* and blue tilapia *Oreochromis aureus* gained entry into the reservoir from nearby culture ponds during hurricane-driven flood events (personal communication, Sergio Rodriguez and Luis Lozano, UANL Biologists). Native species in La Juventud include Mexican tetra *Astyanax mexicanus*, Rio Grande cichlid *Herichthys cyanoguttatus,* western mosquitofish *Gambusia affinis,* and an unidentified Atherind. La Juventud is accessible for public use daily between the hours of 0600 to 2000 by purchasing a 60-peso day pass. During normal hours of operation, common activities include bird watching, barbequing, picnicking, and fishing; non-motorized and small-motor boats are allowed on the water until the reservoir closes to the public for the night; neither water sports nor overnight camping are allowed. If the record of day passes sold at La Juventud is used as an approximation of days fished (Table 1; unpublished data, Sergio Rodriguez, UANL Biologist), then a three-fold increase in fishing pressure has possibly occurred between 1998 and 2006. As a stipulation of the day-pass, anglers must adhere to regulations, which include minimum length, bag, and gear limitations proposed by UANL management staff (Table 2). Although anglers occasionally fish from boats, the majority of fishing activity occurs along the southern and western shores near the entrance, in the park, and along the dam.

Field Data Collections

All fish were collected between November 2006 and June 2008 during four main sampling events (24 November 2006; 25 November 2006; 20 June 2007; 18 November 2007; 24 June 2008; 27 June 2008). Sample sites were stratified across all habitat types (littoral zones of the reservoir and the creek, and open water in the reservoir) to collect a representative number and size range of fish; latitude and longitude were recorded from a Garmin Etrex 12 channel GPS unit. Eighteen shoreline sites were electrofished using pulsed-DC waveforms produced by a Honda EG5000 generator and Coffelt VVP-15 pulsator, mounted on a 4-m-long aluminum boat fitted with two 2.5-m-long fiberglass booms.

A single night-time electrofishing survey was conducted (24 November 2007) so that size structures between day and night samples could be compared. Total shock time (s) was recorded at each site to determine catch per unit effort (CPUE) as an index of relative abundance. Various combinations of voltage and current regimes were used; voltage outputs generally ranged from 400 to 600 V and two to four A in order to stun

Table 1. Record of day passes sold yearly between 1998 and 2006.

Year	Day Passes (Days Fished)
1998	3,947
1999	3,848
200	4,955
2001	7,326
2002	8,194
2003	9,401
2004	12,926
2005	11,892
2006	11,391

Table 2. Bag and length limits for La Juventud.

Species	Daily Bag	Length (cm)
Largemouth Bass	1	60
Channel Catfish	None	None
Common Carp	2	35
Blue Tilapia	2	25

fish for collections. Experimental gill nets (76-m long, five panels of nylon mesh, in 1.25-cm-increments from 2.5 to 7.6-cm-bar width) were set 1-m below the surface at 10 open-water sites for 5- to 6-h periods during the day and collected at dusk in order to avoid entanglement of nocturnally active beavers (25 November 2006; 20 June 2007; 18 November 2007; 24 June 2008; 27 June 2008). Three gill nets were set overnight on 24 June 2008 from 1700 to 0830 hours in an attempt to increase sample size of channel catfish. Time (h) elapsed between gill net set and retrieval was recorded to determine CPUE indices of fish relative abundances. Shoreline seining at La Juventud included daytime sampling events each summer in 2007 and 2008. The sampling month of June was chosen to evaluate the reproductive success of springtime and early summer spawning events typical for largemouth bass populations in the Southeastern United States (Clugston 1966; Conley et al. 2004; Higginbotham 1988) and within the range of seasonal spawning observed for largemouth bass in tropical regions (Dadzie and Aloo 1990; Waters and Noble 2004). A total of 360 meters (18 sites) of shoreline were seined in 2007, and 220 meters (11 sites) were seined in 2008. A total of 360 meters (18 sites) of shoreline were seined in 2007 and 220 meters (11 sites) were seined in 2008. Sites were sampled with a bag seine (7.6-m long, 1.9-m deep, with 0.5-cm mesh); 20-m long hauls were made parallel to the shore in 1-m deep water (June 2007; June 2008). Length of captured fish and area seined (seine length x distance seined) were recorded for each haul to determine CPUE indices of abundance to estimate fish relative abundance.

To characterize water quality at open water areas throughout the reservoir the Hydrolab Quanta-4 water quality meter was used at 22 fish-collection sites and additional randomly chosen sites (67 depth-profiles total) from 2006 to 2007; in 2008, 13 surface measurements were taken with a YSI-85 to characterize water quality at seine collection sites. Water temperature (ºC), pH, dissolved oxygen (DO) concentration (mg/l), percent saturation (%), specific conductivity (mS/cm³), turbidity (Nephelometric Turbidity Units, NTU), and total dissolved solids (TDS, mg/l) were recorded for use in habitat analysis and as potential explanatory variables for multivariate analysis of the fish assemblage. Predominant habitat categories that were recorded as present or absent at a collection site were rock (largest diameter > 25 cm), gravel (largest diameter < 5 cm), macrophytes, rooted trees, undercut banks, bare bottom, soft clay and shale.

Laboratory Data Collection

Weight, length, and age data were collected from the two most common recreational species in La Juventud, largemouth bass and channel catfish. Fish collected in electrofishing and gill net samples were preserved with ice and transported to the biology laboratory of the Facultad de Agronomia UANL, where they were identified to species level, counted and further processed. Total length (mm) was measured with a Wildco multi-metric fish-o-meter measuring board and weight (g) was recorded with a triple-beam balance calibrated for accuracy using brass standards. Large fish (> 1000 g) surpassed the capacity of the triple beam balance and were measured (g) with a heavy-duty triple-beam balance calibrated for accuracy. Sagittal otoliths were removed from largemouth bass and channel catfish for age determination. Otolith processing methods followed the descriptions of Buckmeier and Howells (2003) for largemouth bass, and Buckmeier et al. (2002) for channel catfish. Sectioned otoliths were viewed across the transverse plane under a dissection microscope aided by a 1-mm fiber optic cable concentrating and directing light from a 150-Watt lamp. Age was determined by counting annular rings (annuli) formed during alternating periods of fast (spring and summer) and slow (fall and winter) growth (Devries and Frie 1996). Following preliminary examination of otoliths, young-of-the-year were recorded as age 0 based on length: largemouth bass (<150 mm TL) and bluegill (<80 mm TL).

Data Analyses

Length

To evaluate growth, recruitment, and mortality, fish lengths were summarized into length-frequency distributions (1.0-cm TL intervals). Interval width was determined by maximum fish length; as suggested by Anderson and Neumann (1996), 1.0-cm intervals for species that reach 30-cm, 2.0-cm intervals for species reaching 60-cm, and 5.0-cm for species reaching 150-cm. Samples were separated by gear type (electrofishing, gill net, and seine) for analyses. Gablehouse categories of increasing length (Stock, Quality, Preferred, Memorable, and Trophy; derived from Weithman's fish-quality world-record length relationship) were also used to summarize length data into categories commonly used to calculate structural indices of proportional stock density (PSD) and to describe the quality of fish size for management purposes (Gablehouse 1984). For example, the proportional stock density index (PSD) is the percentage of stock length fish that are quality length or greater (Willis et al. 1993) and comparison of this index to desired objective ranges can be used to evaluate size structure. Proportional stock density indices are binomially distributed but can be approximated by the normal distribution to estimate 95% confidence intervals (CI) if values are not too close to either 0 or 100, or if the sample size is large (PSD as decimal fraction × number of stock length fish in a sample < 5.0) (Gustafson 1988).

Statistical analyses were performed with the SPSS 15.0 statistical analysis program (SPSS, Inc, Chicago, Illinois). Kolmogorov-Smirinov (K-S) tests were used to test length-frequency distribution differences among years, gears, and times of day. The K-S test includes no underlying assumptions about data distribution and is appropriate for multi-modal and skewed length frequency data. The K-S test is sensitive to differences in both location and shape; sample data must be centered around the mean to eliminate differences in location so that shape; thus, sample data must be centered around the mean to eliminate differences in location so that shape can be compared. can be compared. The SPSS statistical software calculates the following: a K-S statistic (Z), the largest absolute distance between cumulative distribution functions (D), and significance level (P) for sample data and centered sample data. The null hypothesis (Ho) is rejected (at the alpha probability level ≤ 0.05) when the Z surpasses a critical value, provided by the SPSS statistical software (Neumann and Allen 2007; Sokal and Rohlf 1981).

Age, growth, and mortality

Otolith data were used to evaluate population age structure, year-class strength, mortality, and growth. All statistical analyses were performed with the SPSS 15.0 statistical analysis program (SPSS, Inc, Chicago, Illinois). The K-S test was used to determine if age-frequency distribution differed among years, and between electrofishing and gill netting collections. To evaluate growth for major sportfish (largemouth bass and channel catfish), length-at-age values were tested for differences among years 2006, 2007, and 2008, using analysis of covariance (ANCOVA) and were compared to the mean of means for length-at-age values of largemouth bass populations from the southern United States, the mean-length at age values from a reservoir in Puerto Rico, and the average growth values in Texas recreational ponds (Beamesderfer 1995; Conley et al. 2004; Ozen 2000; Ozen 2005). Using the Fisheries Analysis and Simulation Tools (FAST) software program (Slipke and Maceina 2001), the length-at-age relation was also described using the von Bertalanffy (von Bertalanffy 1957) growth equation

$$Lt = L\infty\left(1 - e^{-k(t - to)}\right)$$

$L\infty$ = maximum theoretical length that can be obtained

k = growth coefficient

t = time in years

t_o = time in years at which length is theoretically equal to zero

e = exponent of natural log

and iterative non-linear regression that minimizes the sum of squares so that parameters for length-at-infinity ($L\infty$), growth coefficient (K), and time (i.e., years) at which length theoretically is equal to zero (t_0) could be compared to the average values of these parameters for populations in Florida and to values for one reservoir population in Puerto Rico (Beamesderfer and North 1995; Ozen and Nobel 2000).

Catch curves representing the decline in number of fish across age-classes were used to evaluate mortality. To determine interval mortality (A) and survival (S) rates, weighted linear regressions were run using SPSS, to estimate the slopes or instantaneous mortality rates (Z) of log-frequency age-class plots. Ricker (1975) stated that moderate and random variations in recruitment should not change the general form of a catch curve, thus allowing mortality rates to be estimated; however, to increase the sample sizes of older age groups and to meet the assumptions of constant recruitment and equal catchability across years and age groups, catch-at-age data were pooled across years and restricted to only those age classes considered fully recruited to the gear (Devries and Frie 1996; Miranda and Bettoli 2007).

Minimum-length evaluation

Using FAST software (Slipke and Maceina 2001), the weight:length relation was computed. Parameters of the weight:length function and von Bertalanffy growth function were then integrated in a modification (Jones 1975) of the Beverton-Holt equilibrium yield model (Ricker 1975)

$$Y = \frac{F \bullet N_t \bullet e^{Zr} \bullet W\infty}{K} \beta(X, P, Q)$$

F = instantaneous fishing mortality

Nt = $N_0 \bullet e^{-M\left(t_r - t_0\right)}$

M = instantaneous natural mortality

tr = age of recruitment to the fishery

to = hypothetical age at which the fish length would be 0 mm, from the von Bertalanffy equation

Z = M + F, total instantaneous mortality

r = tr – to, time in years to recruit to the fishery

W∞ = asymptotic weight derived from L∞ and the weight:length function

β = incomplete beta function, computed by FAST

X = e^{-kr}

P = Z/k

Q = slope of the weight-length relation + 1

to simulate the effects of hypothetical length limits on angler yield and harvest while holding constant the effects of recruitment, conditional fishing mortality, and conditional natural mortality. Conditional fishing mortality is the expected exploitation rate in the absence of natural mortality, and conditional natural mortality is the expected death rate in the absence of fishing (Ricker 1975). The only variable that is manipulated is the length when fish enter the fishery. In my study, this is based on different values for a fixed minimum length limit.

RESULTS

Water Quality and Habitat

Mean (and maximum) depths determined from random depth profiles during November were 1.1 m (3.8 m) in 2006, and 1.3 m (2.9 m) in 2007. Mean water turbidity ranged from 74 to 185 NTU, and specific conductivity ranged from 1.07 to 2.13 mS/cm^3, and considered consistent with conditions of low light availability, low water hardness, and low measured TDS (Table 3). Soft clay was the predominant substrate type throughout the reservoir and tributary creeks. Differences in dissolved oxygen (DO) between fall (2006) and summer (both 2007 and 2008) were consistent with expected seasonal changes; vertical differences in water column DO were greatest in summer 2007 when DO concentrations at the bottom of the reservoir approached 0 mg/L. Mean values remained near pH 8 among seasons and years.

Largemouth Bass Population Characteristics

Size structure and abundance

In 2006, for day-time ($N = 31$) versus night-time ($N = 39$) electrofishing samples, K-S tests indicated no differences in location ($D = 0.174$; $P > 0.10$) or shape ($D = 0.147$; $P > 0.10$) of length frequency distributions (Figure 3). Electrofishing collections of largemouth bass did not differ in location ($D = 0.189$; $P > 0.10$) or shape ($D = 0.168$; $P >$

Table 3. Water parameters measured in La Juventud Reservoir. Measurements were collected in 2006 and 2007 at 1-m depth profiles and in 2008 at the waters surface. Values in parentheses are sample sizes.

Parameter	Fall 2006 Mean Values			Summer 2007 Mean Values			Fall 2007 Mean Values			Summer 2008 Mean Values
	Surface	Bottom	Total	Surface	Bottom	Total	Surface	Bottom	Total	Surface
Physical										
Water Temperature (°C)	19.19 (15)	17.56 (7)	18.48 (31)	31.06 (7)	27.06 (6)	29.54 (23)	22.88 (8)	20.53 (4)	22.21 (14)	28.49 (13)
Sp. Conductivity (mS/cm³)	1.10 (14)	1.07 (7)	1.08 (25)	1.71 (7)	1.70 (6)	1.70 (23)	1.45 (7)	1.44 (4)	1.44 (13)	2.13 (13)
Chemical										
Dissolved Oxygen (mg/L)	9.79 (15)	7.62 (7)	8.95 (31)	7.10 (7)	2.10 (6)	5.12 (23)	--	--	--	7.08 (13)
Oxygen Saturation (%)	109.41 (14)	82.20 (7)	98.40 (30)	63.20 (4)	39.15 (4)	56.18 (13)	--	--	--	96.88 (13)
pH	8.50 (15)	8.26 (7)	8.41 (31)	8.33 (7)	8.04 (6)	8.26 (23)	8.26 (8)	8.01 (4)	8.18 (14)	--
Turbidity (NTU)	87.75 (15)	185.00 (6)	106.33 (30)	83.46 (7)	--	91.31 (17)	73.87 (8)	143 (2)	86.55 (14)	--
Total Dissolved Solids (mg/L)	0.73 (15)	0.70 (7)	0.71 (31)	--	--	--	0.91 (8)	0.90 (4)	0.91 (14)	--

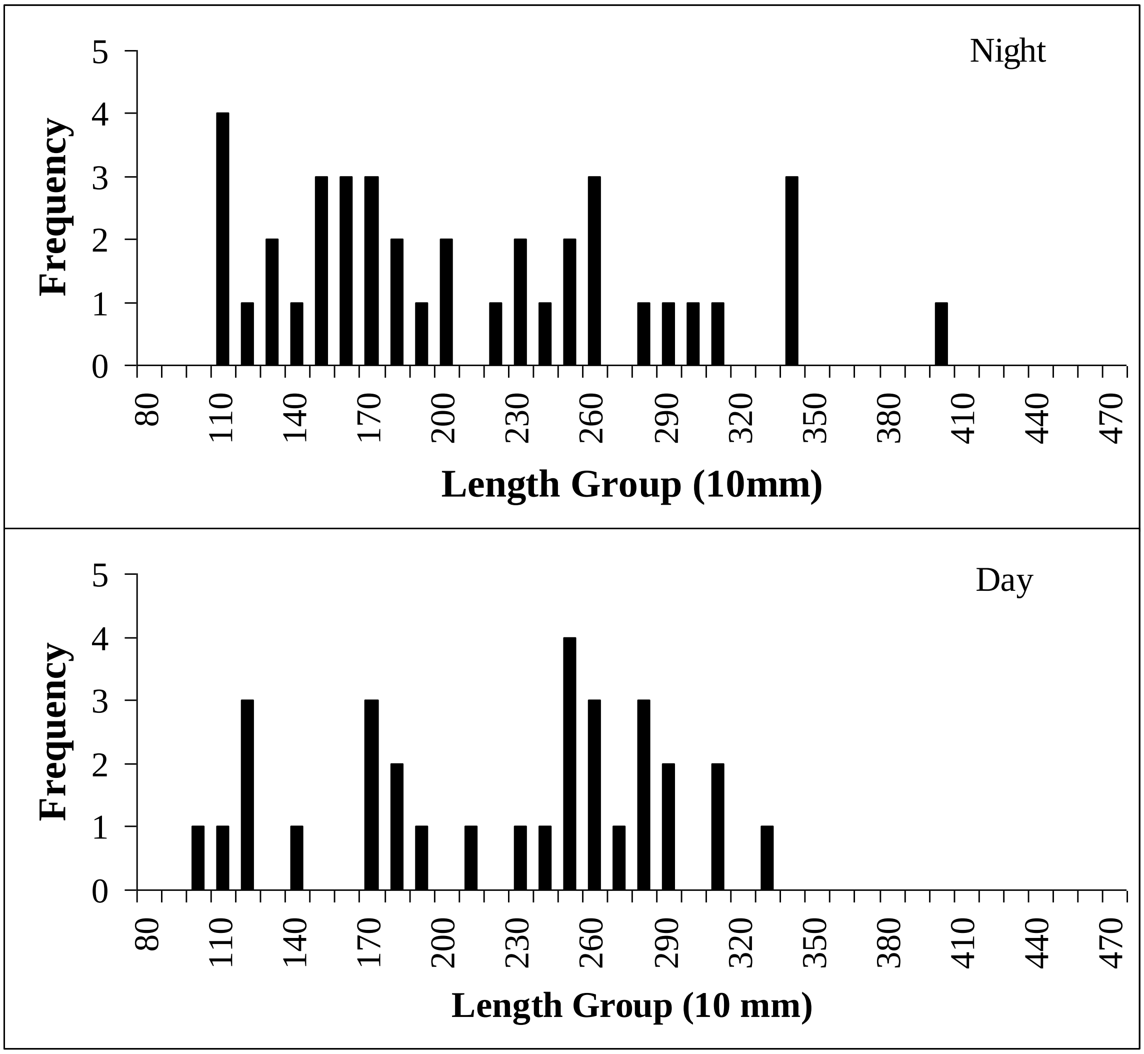

Figure 3. Night-time and day-time largemouth bass size structure. Length-frequency distribution of largemouth bass electrofished in November 2006, during night and day in La Juventud Reservoir, Nuevo Leon, Mexico.

0.10) for length frequency distributions in 2006 (N = 70; mean TL = 219 mm; SD = 71.1 mm; Figure 4) and 2007 (N = 44; mean TL = 226 mm; SD = 92.8; Figure 4). To increase sample size and size-structure representativeness for gill net data, length frequency distributions of largemouth bass captured in 2006 - 2008 were pooled (N = 74; mean TL = 266 mm TL; SD = 53.3; Figure 5).

Due to the size selective properties of the collection gears, I pooled length frequency distributions for between-gear comparisons using only stock length and longer largemouth bass (≥ 200 mm), which were considered to be fully recruited to both gears (Figure 6); no significant differences in location (D = 0.235; P > 0.05) or shape (D = 0.094; P > 0.10) were found.

Only the largemouth bass in 2007 electrofishing samples met the generally accepted PSD objective (40) for a balanced largemouth bass and sunfish management strategy (Table 4). The number of stock length fish collected in 2006 and 2007 gill net samples were too small to produce precise C. I. estimates for PSD, and therefore PSD was not calculated. Most largemouth bass were sub-stock (0 – 199 mm) and stock size (200 – 299 mm), and although quality size (300 – 379 mm) individuals were collected in each year, preferred length (380 – 509 mm) fish were rare (Figures 7 and 8). Electrofishing catch rates indicated low densities of stock-length largemouth bass and that about half of all fish captured by electrofishing were smaller than 200-mm TL (Table 4).

Age structure and recruitment

All of the 114 largemouth bass collected by electrofishing were aged (70 in 2006 and 44 in 2007). Ages estimated from annuli counts ranged from 0 to 4 years in 2006 and 0 to 7 years in 2007 (Figure 9). Age-5 and age-6 fish were absent from collections and only one age-7 largemouth bass was collected. The K-S tests indicated that age frequencies for electrofished largemouth bass 2006 and 2007 were not different in location ($D = 0.055$; $P > 0.10$), but were different in shape ($D = 0.477$; $P < 0.01$).

All of the 74 largemouth bass collected by gill netting were aged (22 in 2006, 14 in 2007, and 38 in 2008). Ages estimated from annuli counts ranged from 0 to 3 years in 2006, 0 to 6 years in 2007, and 0 to 5 years in 2008 (Figures 10). Age-frequency distribution patterns were not consistent across years. Only one age-6 largemouth bass was sampled in 2007 and neither age-4 nor age-5 largemouth bass were captured in 2006 or 2007. Largemouth bass pooled across years (2006 – 2008) showed that year-class abundance in gill nets decreased sharply after age 3 (Figure 11).

For electrofishing collections, CPUE of age-0 largemouth bass declined from 2006 to 2007, and for shoreline seining collections, CPUE of all largemouth bass approached zero in years 2007 and 2008 (Table 5). Conversely, the electrofishing CPUE of age-0 bluegill increased from 2006 to 2007, and shoreline seining CPUE of recent young-of-the-year bluegill, blue tilapia, and threadfin shad increased from 2007 to 2008. Largemouth bass age-frequency distributions were compared (Figure 12) between electrofishing (pooled across 2006-2007) and gill netting (pooled across 2006-2008). To avoid problems of differential bias between gears, only the pooled length frequency

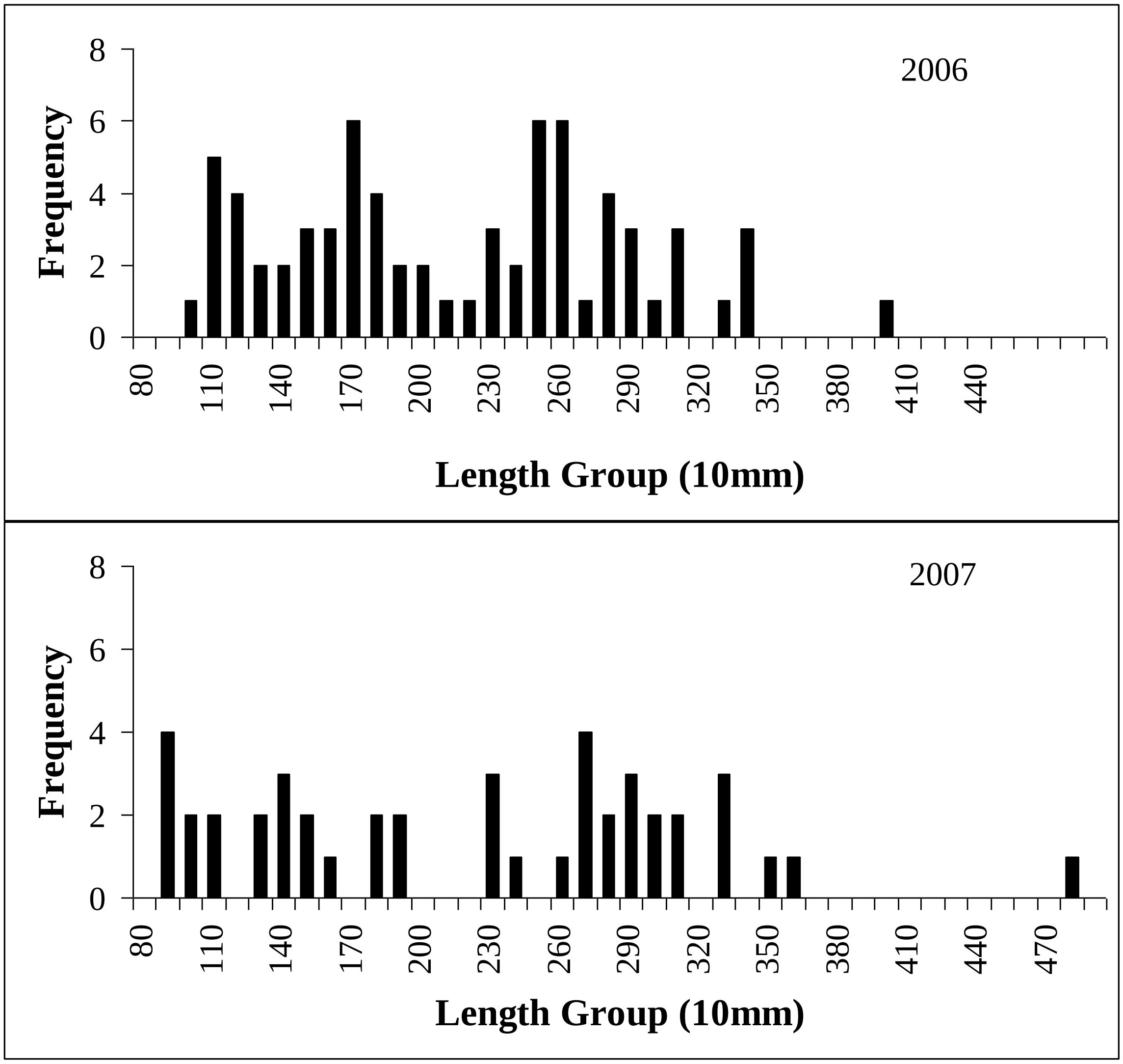

Figure 4. Largemouth bass electrofishing size structure. Length-frequency distribution of largemouth bass electrofished in November 2006 and November 2007 in La Juventud Reservoir, Nuevo Leon, Mexico.

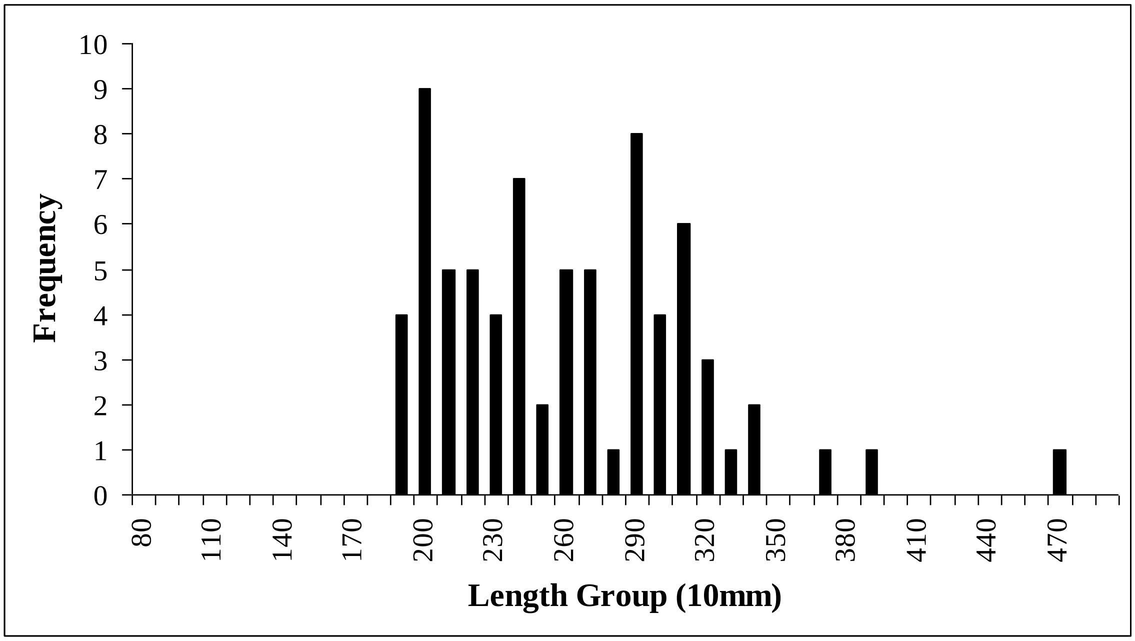

Figure 5. Largemouth bass gill-netting size structure. Length-frequency distribution of gill-netted largemouth bass, pooled across years 2006-2008, in La Juventud Reservoir, Nuevo Leon, Mexico.

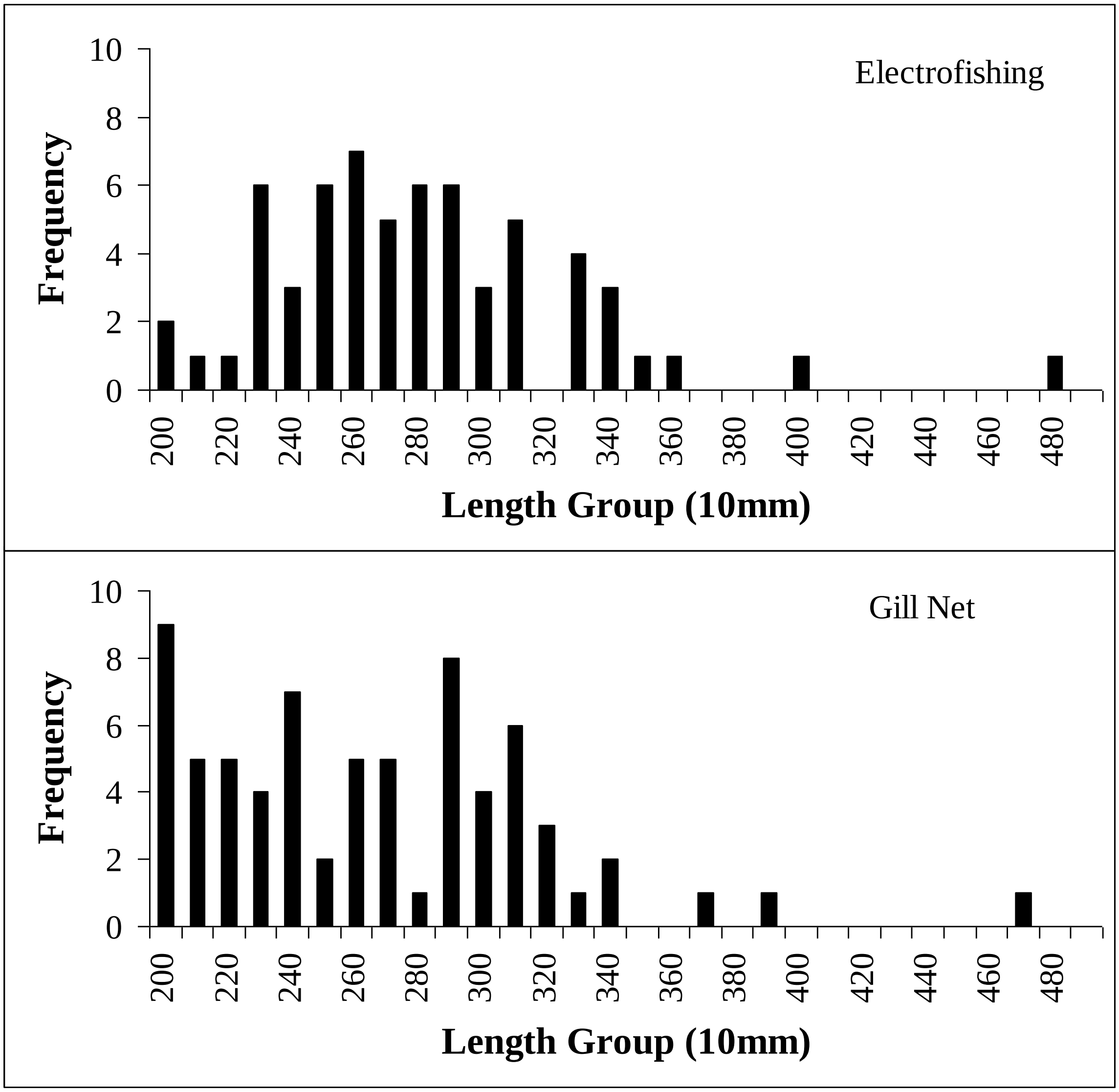

Figure 6. Electrofishing versus gill-netting size structure. Pooled length-frequency distribution of ≥stock-length (200mm TL) largemouth bass sampled by electrofishing 2006-2007 and gill net 2006-2008 in La Juventud Reservoir, Nuevo Leon, Mexico.

Table 4. Largemouth bass stock density indices and CPUE. Proportional stock densities (PSD), number of stock length largemouth bass (N), 95% confidence intervals of stock-length largemouth bass for each year and gear type, and electrofishing catch rates.

	Electrofishing				
				CPUE (fish/hr)	
Year	Effort (hr)	PSD±95% C.I.	N	Stock (≥ 200-mm TL)	Total
2006	1.64	24± 10	38	23.0	43
2007	0.68	42± 15	24	35.2	54
	Gill Net				
Year	Effort (hr)	PSD±	N	--	--
2008	--	16± 4	37	--	--

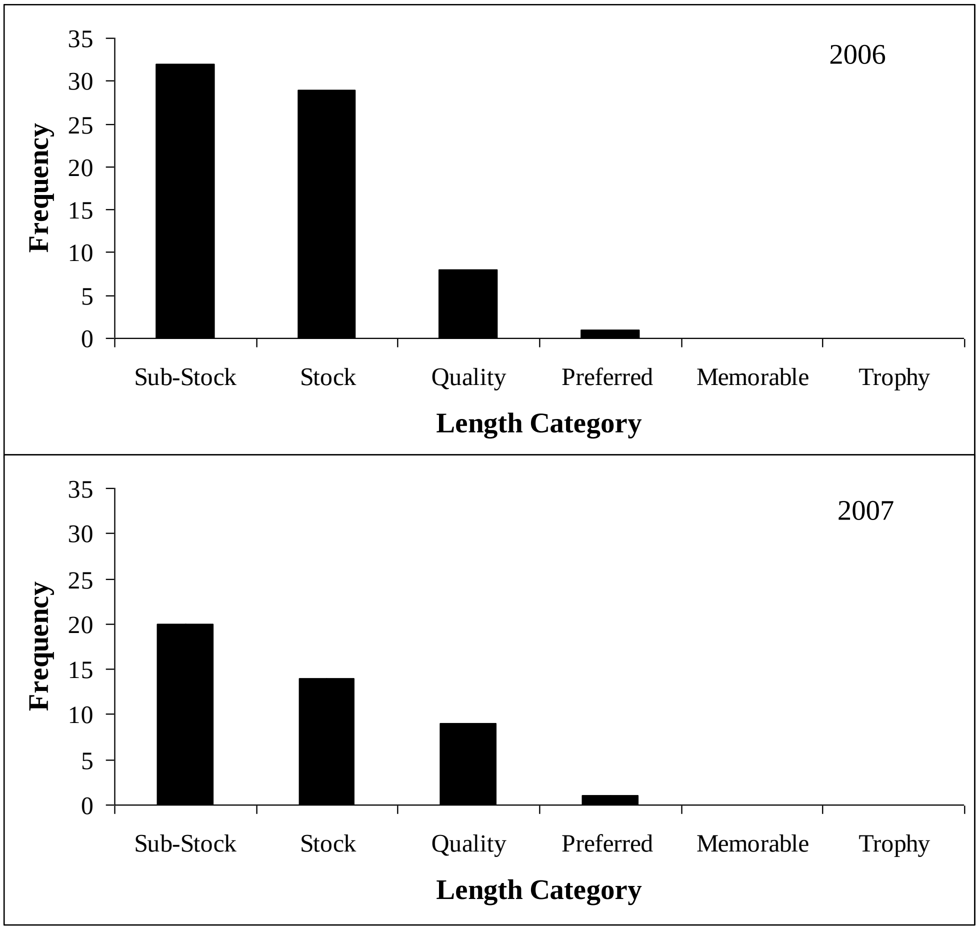

Figure 7. Largemouth bass electrofishing length category distributions. Gablehouse length-category distribution of largemouth bass electrofished in November 2006 and November 2007 in La Juventud Reservoir, Nuevo Leon, Mexico.

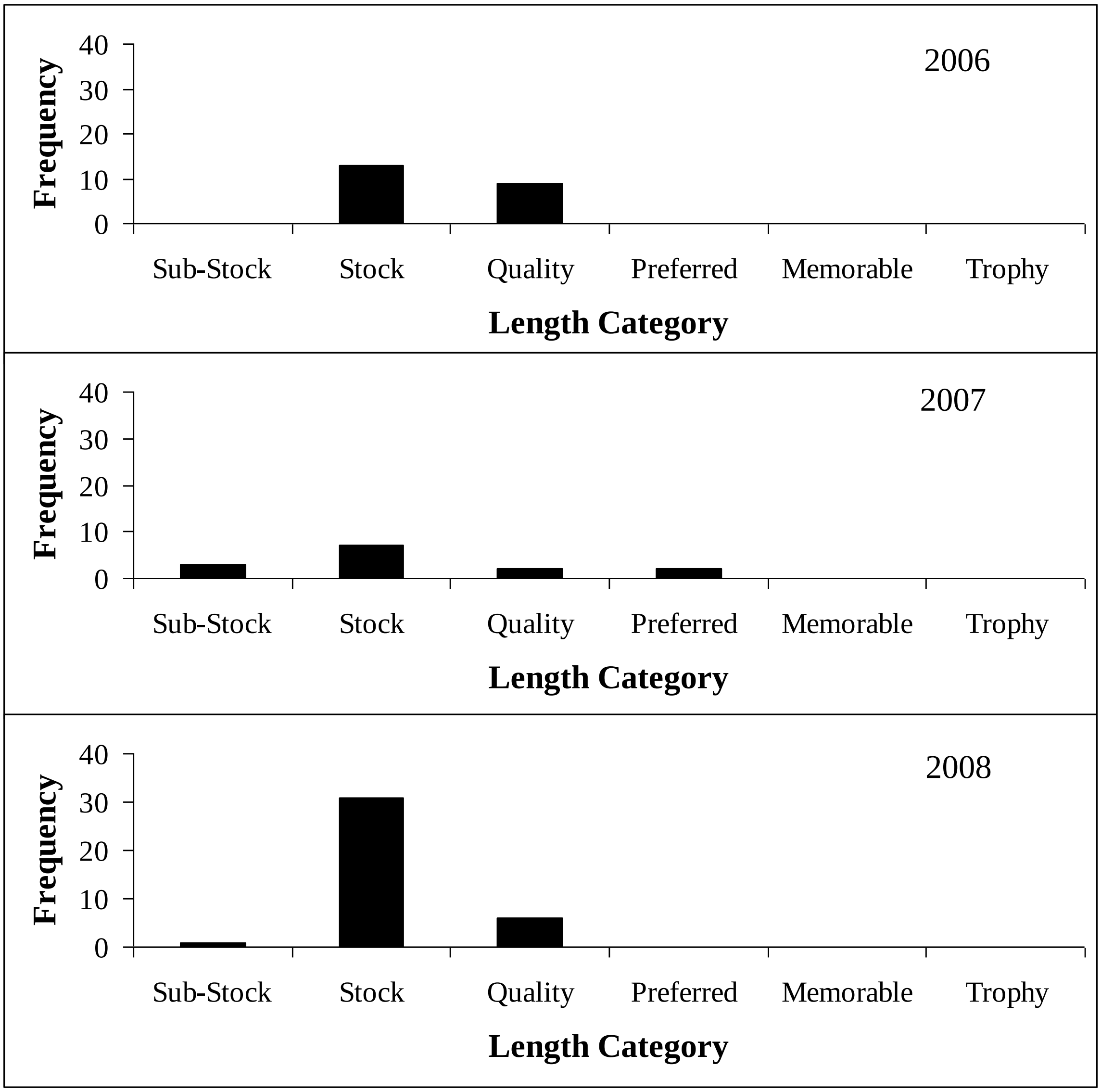

Figure 8. Largemouth bass gill-netting length-category distributions. Gablehouse length-category distribution of largemouth bass gill-netted in November 2006 November 2007 (middle panel) and June 2008 in La Juventud Reservoir, Nuevo Leon, Mexico.

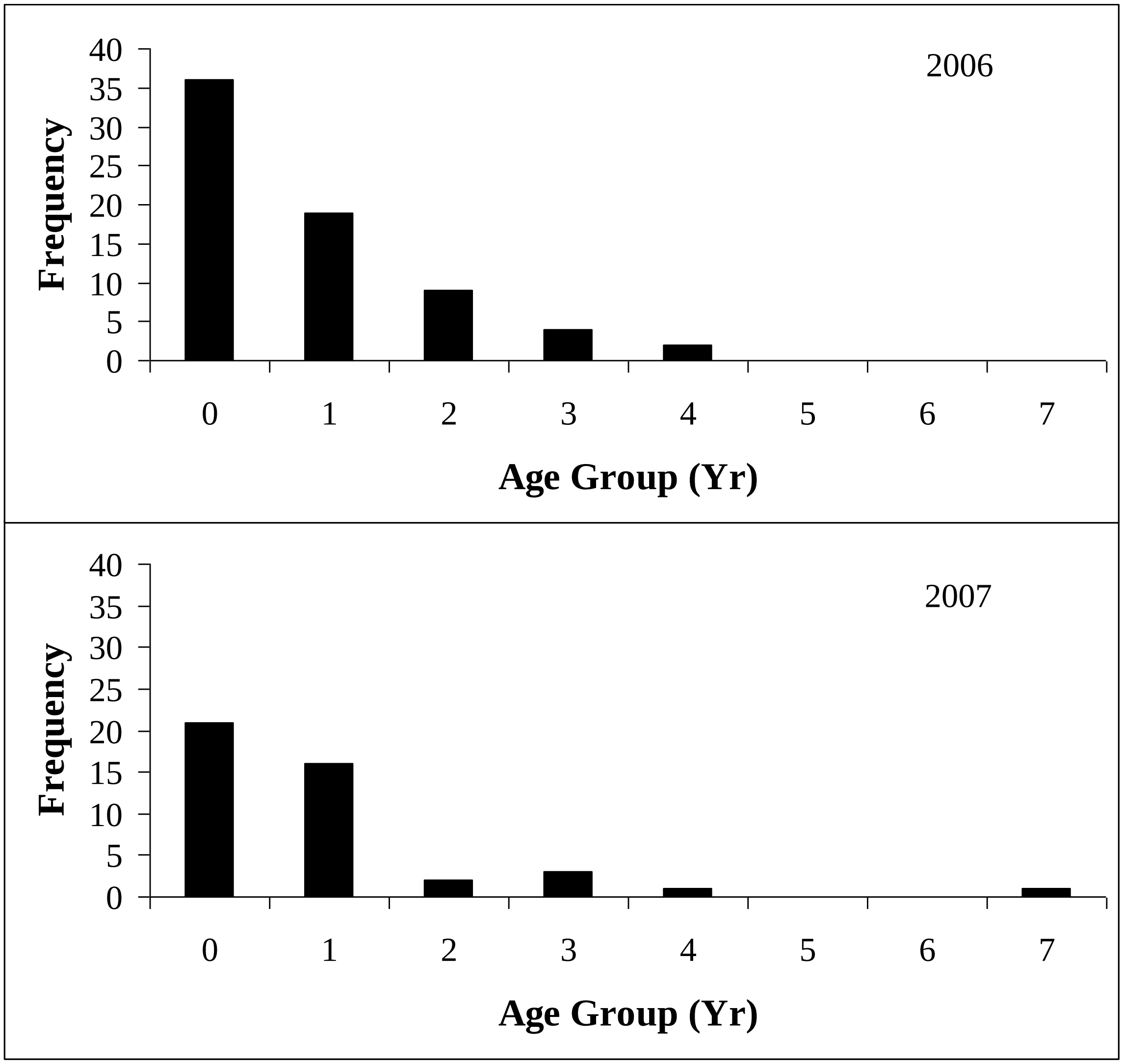

Figure 9. Largemouth bass electrofishing age structure. Age frequency distribution of electrofished largemouth bass in November 2006 and November 2007 in La Juventud Reservoir, Nuevo Leon, Mexico.

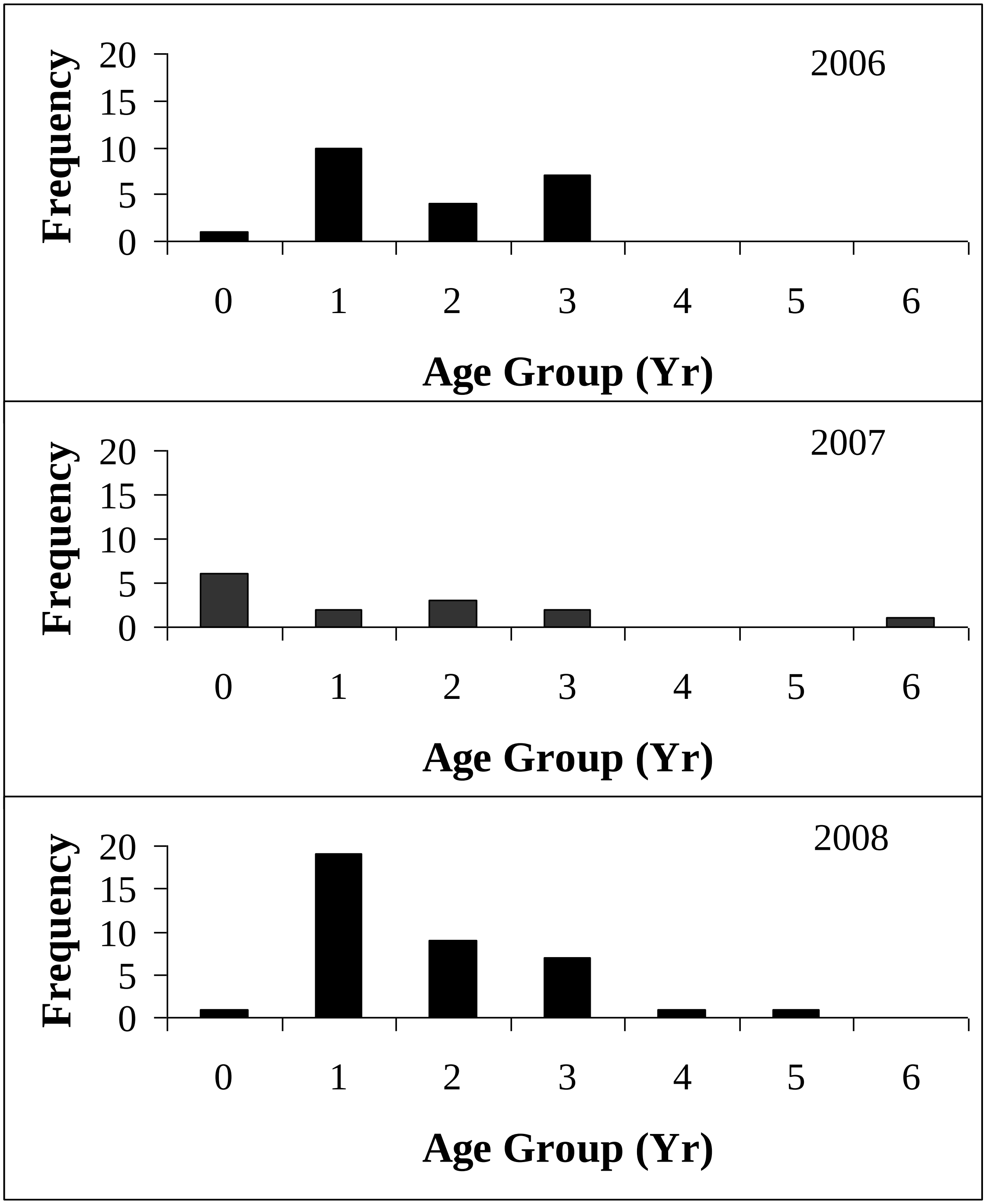

Figure 10. Largemouth bass gill-netting age structure. Age-frequency distribution of gill-netted largemouth bass in November 2006 November 2007 and June 2008 in La Juventud Reservoir, Nuevo Leon, Mexico.

Table 5. Relative abundance of recently hatched centrarchids and blue tilapia. Catch per unit effort (CPUE) for age-0 largemouth bass and bluegill collected by electrofishing during November 2006 and 2007 and for young-of-the-year largemouth bass, bluegill, blue tilapia, and threadfin shad collected by seining during the summer of June 2007 and 2008 in La Juventud Reservoir, Nuevo Leon, Mexico.

		November Electrofishing CPUE
Year	Total Effort (hr)	Largemouth Bass Age-0
2006	1.64	21.8
2007	0.68	30.8

		June Seine Haul CPUE	
Year	Total Effort (m^2)	Largemouth Bass ≤ 150 mm TL	Largemouth Bass > 150 mm TL
2007	360	0.03	0.00
2008	220	0.03	0.08
Year	Total Effort (m^2)	Blue Gill ≤ 80 mm	Bluegill > 80 mm
2007	360	0.00	0.01
2008	220	2.09	0.11
Year	Total Effort (m^2)	Blue Tilapia ≤ 80 mm	Blue Tilapia > 80 mm
2007	360	0.01	0.01
2008	220	2.65	0.01
Year	Total Effort (m^2)	Threadfin Shad ≤ 60 mm	
2007	360	1.23	
2008	220	9.96	

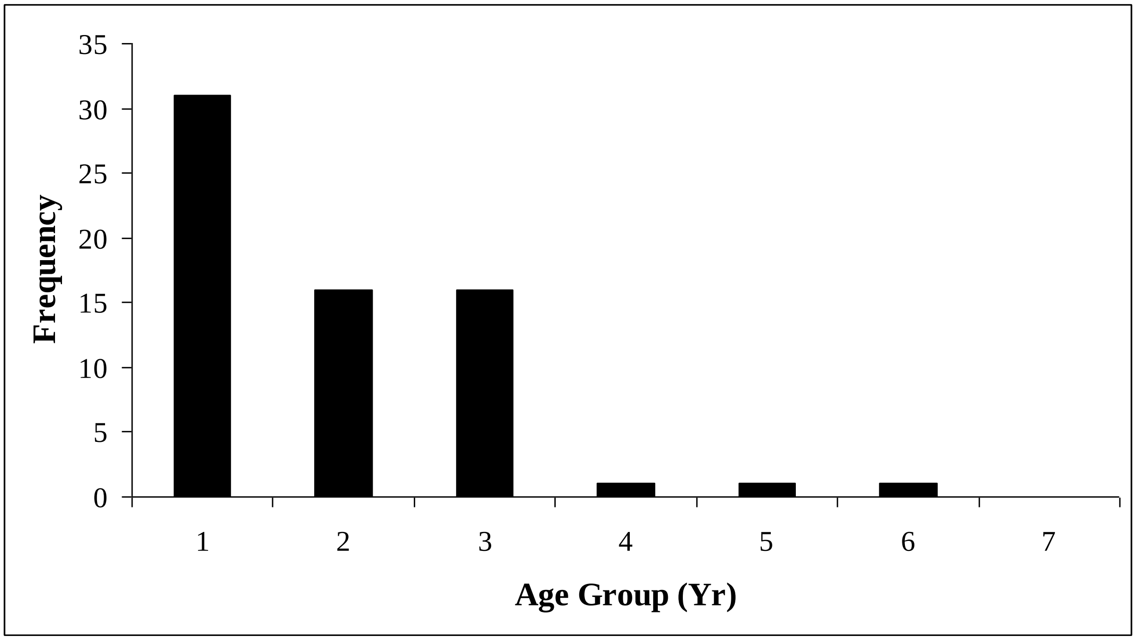

Figure 11. Pooled gill-netting age structure. Age-frequency distribution for gill-netted largemouth bass pooled across years 2006 – 2008 in La Juventud Reservoir, Nuevo Leon, Mexico.

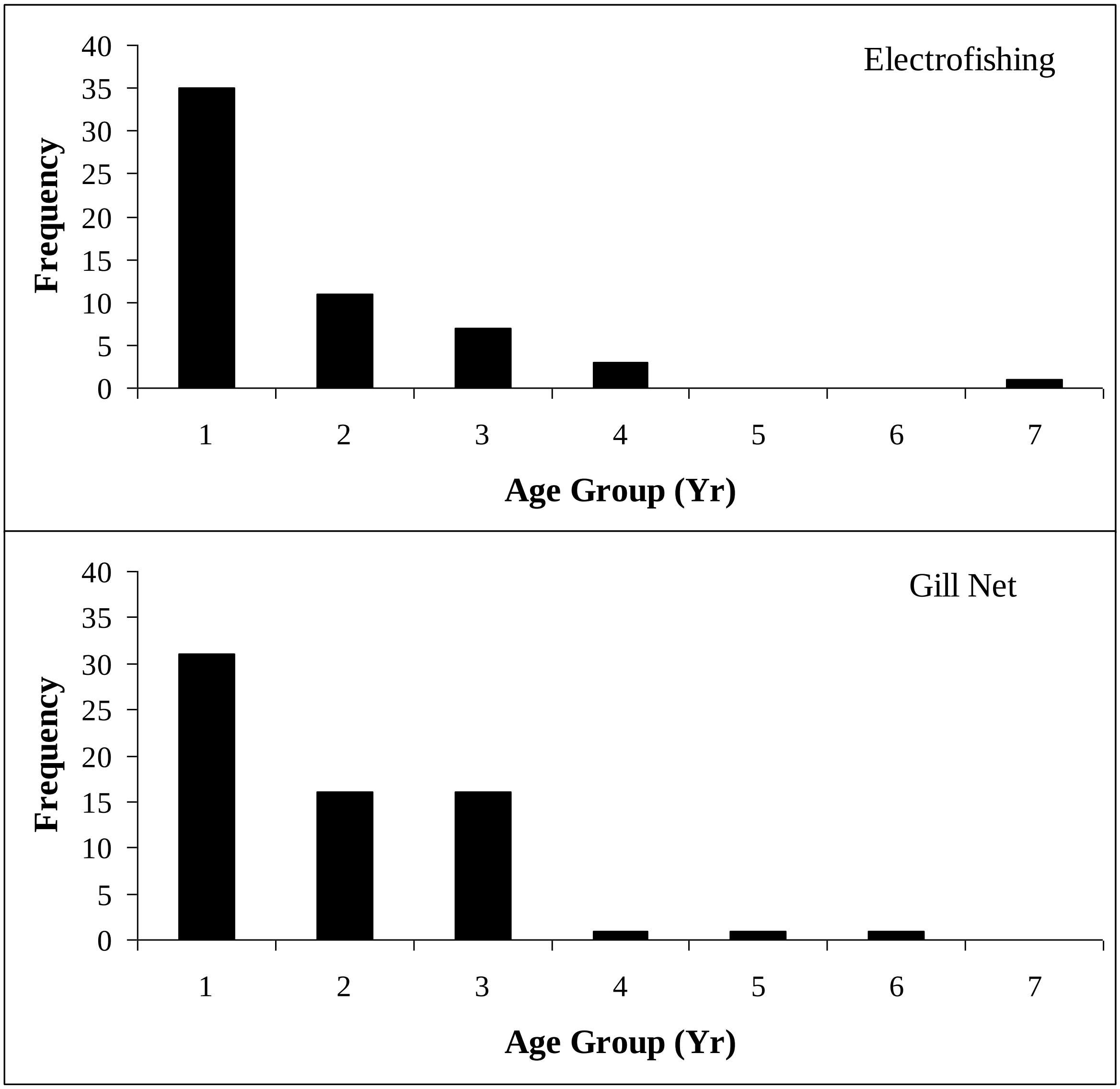

Figure 12. Electrofishing versus gill-netting age structure. Age-frequency distribution of age-1 and older largemouth bass sampled by electrofishing 2007-2007 and gill netting 2006-2008 in La Juventud Reservoir, Nuevo Leon, Mexico.

Growth

Because K-S tests detected no between-gear difference in the length distribution for largemouth bass > 200-mm TL, mean length-at-age values and von Bertalanffy growth parameters for individuals pooled across gears were compared among years. Analysis of covariance indicated that length-at-age slopes differed among years (year × age: $F = 136.139$; $P < 0.01$). Mean length-at-age growth curves indicated that largemouth bass grew to sizes between 200- and 300-mm TL by age-1 (Figure 13), which by comparison, were relatively larger than the mean of mean length-at-age-1 values for largemouth bass populations from the Southeastern U.S.A. and similar to the mean length-at-age 1 value reported for a fast growing population in Puerto Rico (Figure 14) (Beamesderfer and North 1995; Conley et al. 2004; Ozen and Noble 2000; Ozen and Noble 2005). The growth curves for largemouth bass at La Juventud further indicated that fish had generally reached or surpassed 300-mm TL (quality length) by age-3, similar to growth trends exhibited by largemouth bass populations in the Southeastern U.S.A. (Beamesderfer and North 1995) (Figure 13 and 15). Few largemouth bass older than age-3 were collected by electrofishing and gill-netting across years; however, the mean length-at-age and length-at-age values of older fish were often not much larger than mean length-at-age-3 values of younger fish or relatively much larger (Figure 13).

The von Bertalanffy growth model was used to calculate the iterative linear regression for mean length-at-age data that was pooled across years for largemouth bass in La Juventud. The L_∞ of the von Bertalanffy growth equation for largemouth bass in La Juventud was estimated as 456-mm TL with a growth coefficient (k) of 0.297. By comparison, this was smaller than the maximum size (L_∞) reported for Florida populationseven though their k values were similar (Beamesderfer and North 1995; Table 6). Conversely, the k for largemouth bass was much smaller for La Juventud than Lucchetti Reservoir in Puerto Rico (Ozen and Noble 2000) whereas L_∞ was larger for La Juventud fish.

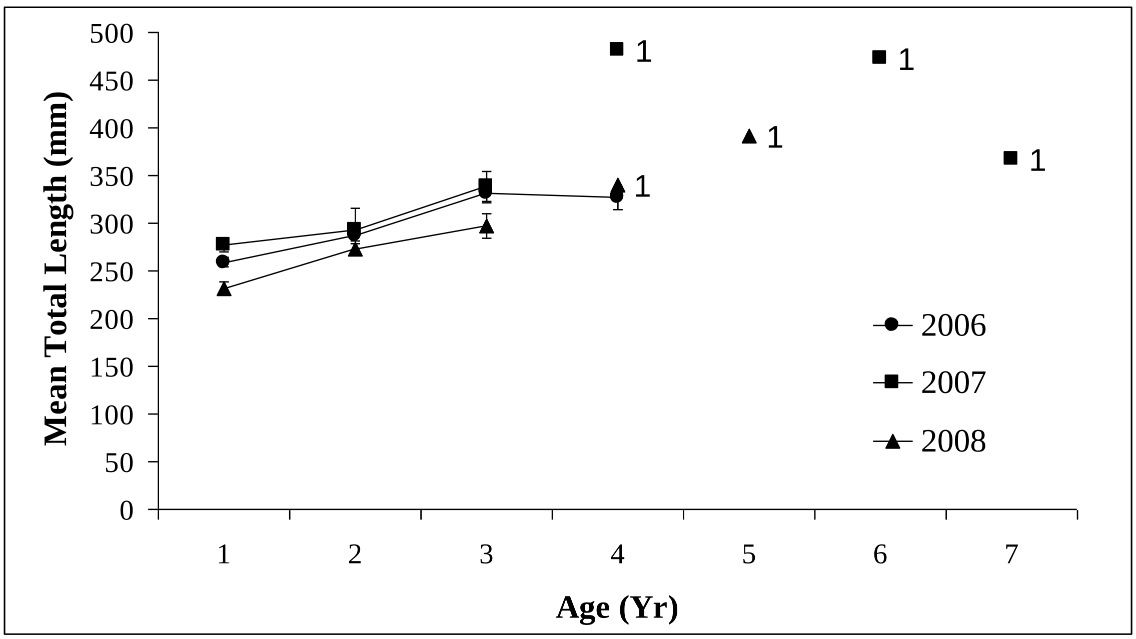

Figure 13. Largemouth bass length-at-age evaluations. Mean length-at-age and length-at-age of electrofished and gill-netted largemouth bass collected from La Juventud Reservoir in 2006, 2007, and 2008.

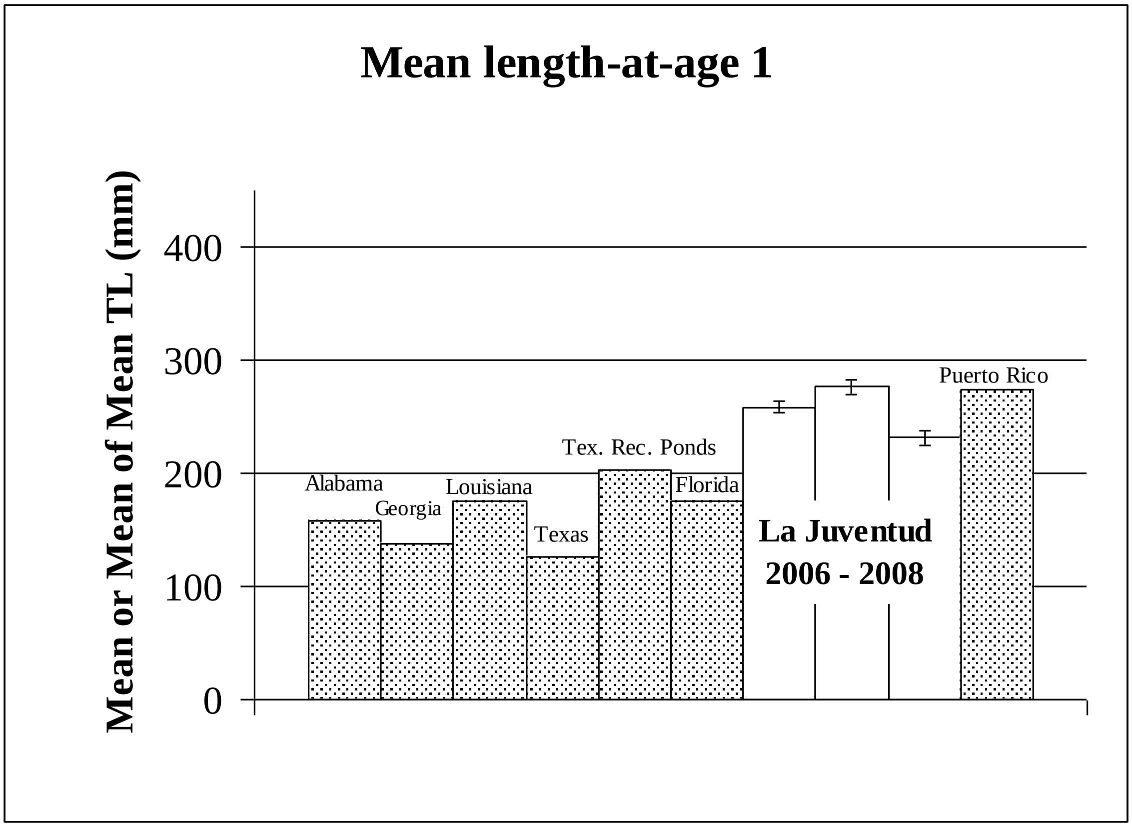

Figure 14. Mean length-at-age-1 comparisons. Mean length-at-age-1 for largemouth bass in La Juventud reservoir compared to mean of mean length-at-age-1 values for largemouth bass populations from the Southeastern Unites States and the mean length-at-age-1 value for a largemouth bass population from Puerto Rico.

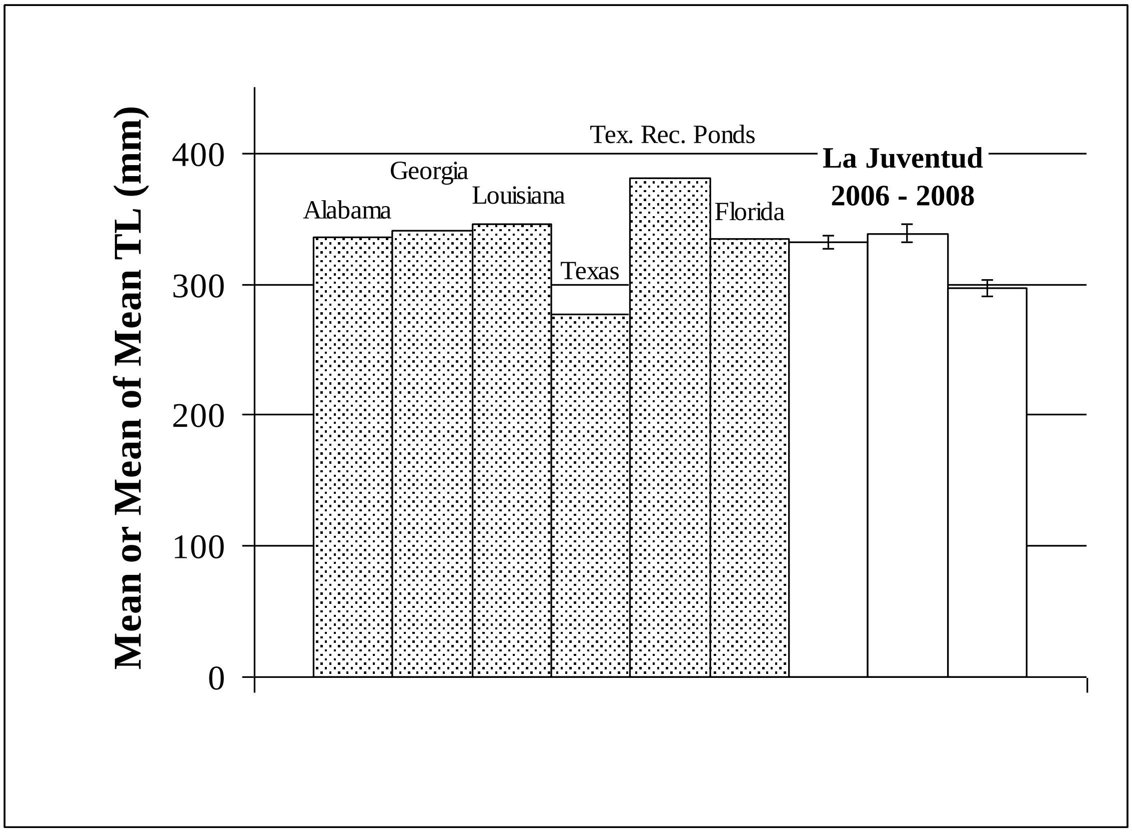

Figure 15. Mean length-at-age-3 comparisons. Mean length-at-age-3 for largemouth bass in La Juventud reservoir compared to mean of mean length-at-age-3 values for largemouth bass populations from the Southeastern Unites States.

Table 6. von Bertalanffy growth parameters. Growth terms length infinity ($L\infty$), growth coefficient (K), and time in years at which length is theoretically zero (t_0) were calculated from length-at-age data from largemouth bass collected by electrofishing and-gill netting at La Juventud reservoir in November 2006, and November 2007 (convergence criteria not me for fish in 2008).

	Florida (Average 14 populations)	La Juventud (Average of 2006 and 2007)	Puerto Rico
Latitude	29°N	25°N	18°N
$L\infty$	619	456	404.4
K	0.260	0.297	1.440
T_0	--	-2.21	0.21

Mortality and minimum length limit evaluations

Based on the catch-at-age (Figure 16), interval mortality rate (A) calculated using electrofishing data was 53% ($N = 101$; $df = 2$; $P < 0.05$), whereas for gill-netting was 20% ($N = 72$; $df = 2$; $P > 0.05$). Due to the uncertainty of actual exploitation and natural mortality at La Juventud, yield (kg) and number of fish harvested per 100 recruits were modeled over a range of parameter settings for conditional fishing mortality and natural mortality (Table 7). Furthermore, only length and age data pooled across electrofishing and gill-netting collections in 2007 were used to compute growth because few largemouth bass older than age-3 were collected in 2006 (these data also appeared to be skewed towards younger fish). The minimum-length limit of 600-mm TL (set by UANL faculty) could not be evaluated because largemouth bass of 600-mm TL were not captured in any of the electrofishing or gill netting collections in La Juventud. Instead, I evaluated length limits of 200-, 300-, and 380-mm TL because they coincide with Gablehouse minimum length categories and can be used to evaluate changes in yield and harvest over a commonly applied range of fishing regulations in southern North America.

By holding conditional natural mortality constant at 20% (Figure 17), higher yields (kg) were predicted under a 300-mm minimum length limit if exploitation rates were < 40%, and under a 380-mm minimum length limit if exploitation rates were > 40%; under a 200-mm TL length limit yields declined if exploitation rates were > 30%. By holding conditional natural mortality constant at 40% (Figure 17), higher yields (kg) were predicted under a 200–mm length limit if exploitation rates were < 40%, and also under a 300-mm TL length limit if exploitation rates were > 40%.

For simulated conditional natural mortalities of 20 and 40 %, the number of fish harvested increased as minimum length limits decreased (Figure 18). By holding conditional natural mortality at 20%, about 58% more fish could be harvested by using a 200–mm than a 300–mm TL minimum length limit. Comparing these yields to a 380-mm minimum, about 94% more fish could be harvested by using a 200-mm limit and 47% more fish by using a 300-mm length limit (Figure 18). By holding conditional natural mortality at 40%, about 100% more fish could be harvested by using a 200-mm than a 300-mm minimum length limit. Comparing these yields to the 380-mm minimum, about 460% more fish could be harvested by using a 200-mm minimum and 180% more by using a 300-mm minimum (Figure 18).

Channel Catfish Population Characteristics

Size structure

A total of 52 channel catfish were captured in gill net samples, but number of captured fish varied among years 2006 (23), 2007 (13), and 2008 (16). Total length ranged from 180 to 727 mm ($N = 52$; mean TL = 350 mm, $SD = 130.2$). The K-S test revealed that length-frequencies of gill-netted catfish differed between years 2006 and 2007 in location ($D = 0.826$; $P < 0.01$) but not in shape ($D = 0.385$; $P > 0.10$). In 2006 all channel catfish were less than quality-length (410 mm TL; Figure 20); in 2007 only one

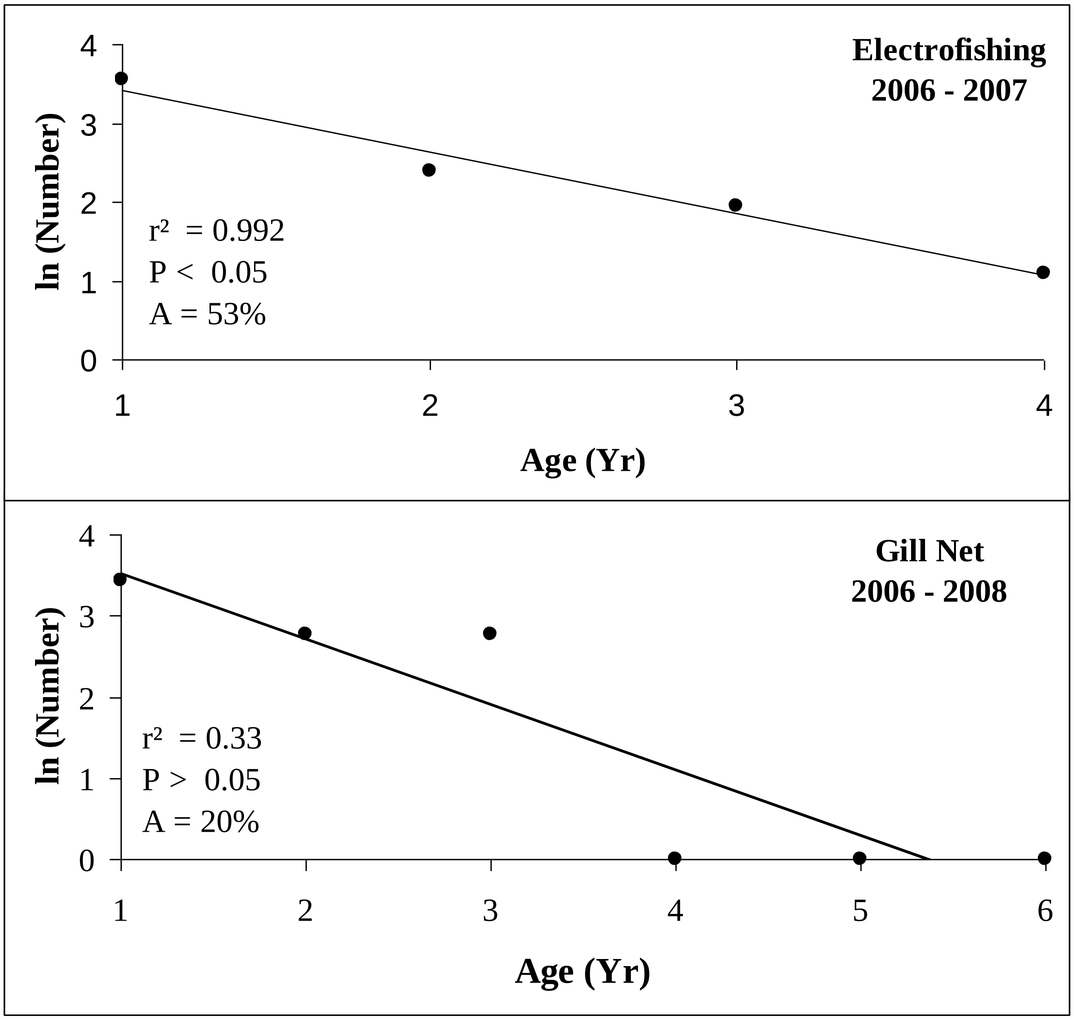

Figure 16. Catch-at-age data for largemouth bass. Linearized catch curves for largemouth bass collected by electrofishing in November 2006 and 2007 and gill-net in November 2006, November 2007, and June 2008 at La Juventud Reservoir, Nuevo Leon, Mexico.

Table 7. Equilibrium yield model parameters. Population dynamic model parameters used to estimate yield for the largemouth bass fishery at La Juventud Reservoir, Nuevo Leon, Leon Mexico.

Variable or Parameter	Definition
Recruitment	100 fish/year (N_0) into the population at t_0
Growth	von Bertalanffy Equation: $L\infty$ = 481, k = 0.329, t_0 = -1.481 Regression Equation of weight (WT) to total length (TL): $WT = 0.00001268\ TL^{3.01}$
Natural mortality	Conditional rates of natural mortality were: 20 and 40% and started at age t_0.
Exploitation	Conditional rates of fishing mortality ranged from 20 to 80% at 10% intervals and started at age t_r.

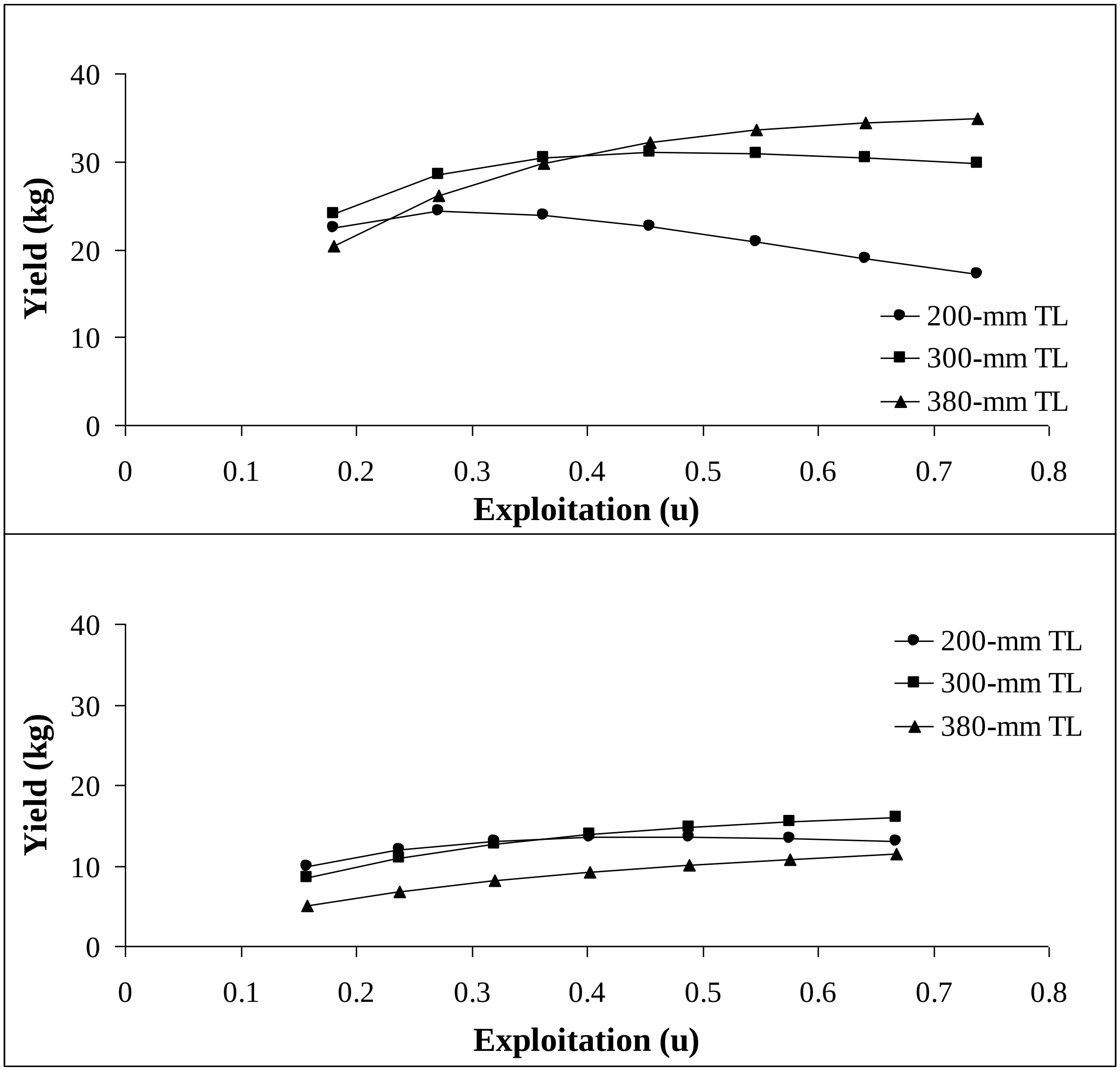

Figure 17. Yield versus exploitation. Yield (kg) per 100 recruits for 200-, 300-, and 380-mm length limits with conditional natural mortality rates of either 0.2 (top panel) or 0.4 (bottom panel) for conditional fishing mortality rates of 0.2-0.8.

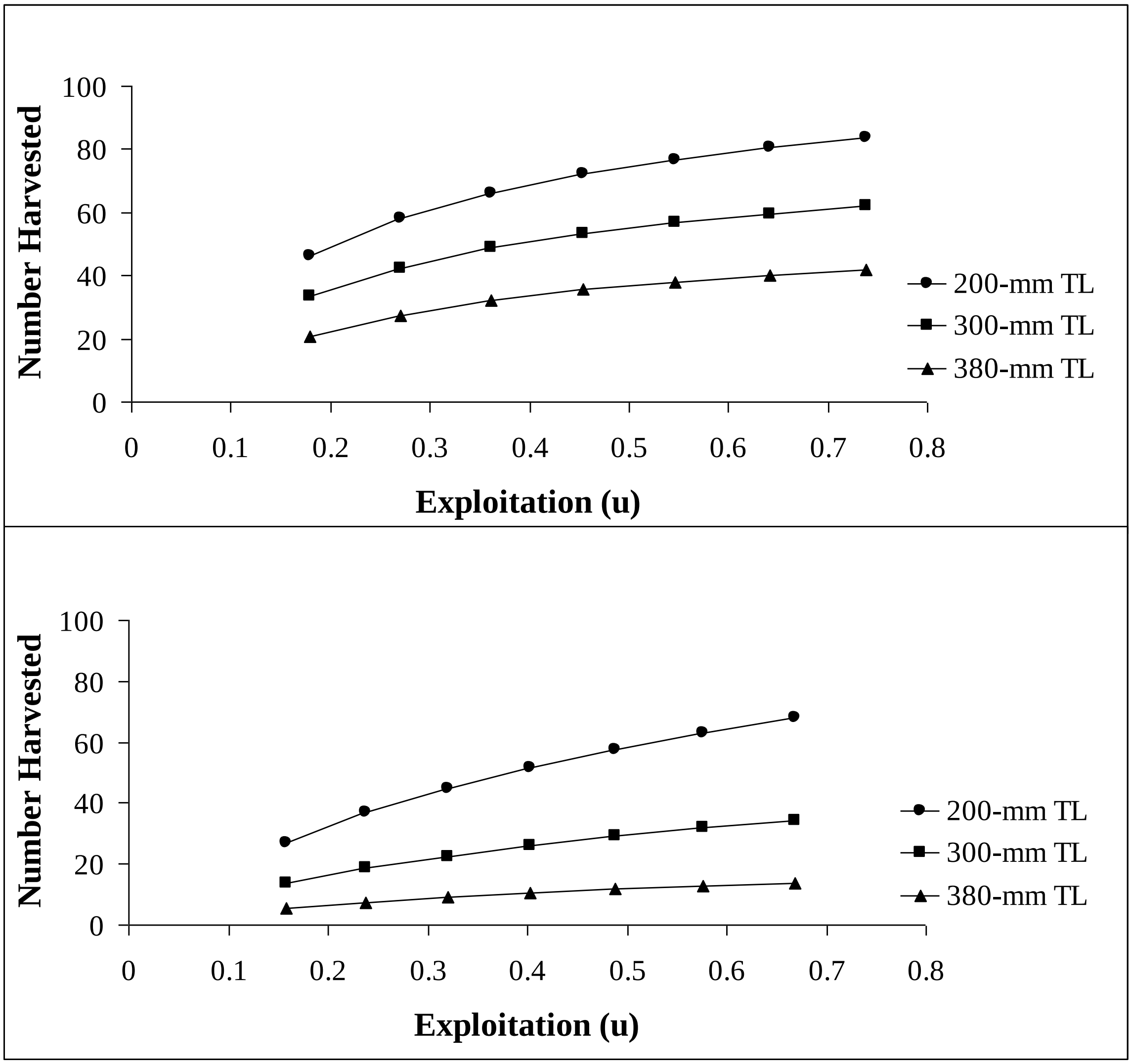

Figure 18. Number of fish harvested versus exploitation. Number of fish harvested per 100 recruits for a 200, 300, and 380 mm length limits with conditional natural mortality rates of 0.2 (top panel) and 0.4 (bottom panel) for conditional fishing mortality rates of 0.2-0.8.

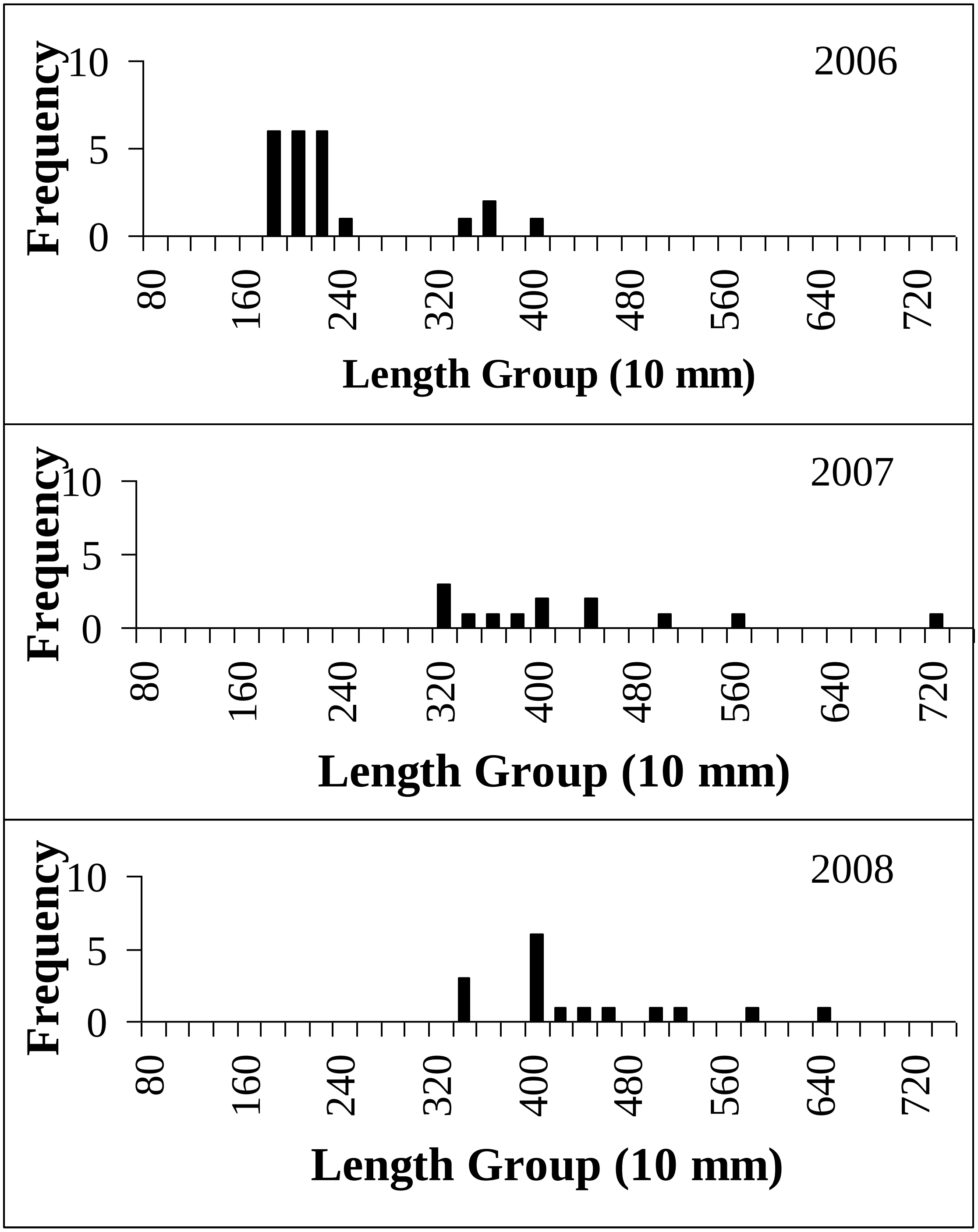

Figure 19. Channel catfish size structure. Length-frequency distribution of gill-netted channel catfish in November 2006 November 2007 and June 2008 in La Juventud Reservoir, Nuevo Leon, Mexico.

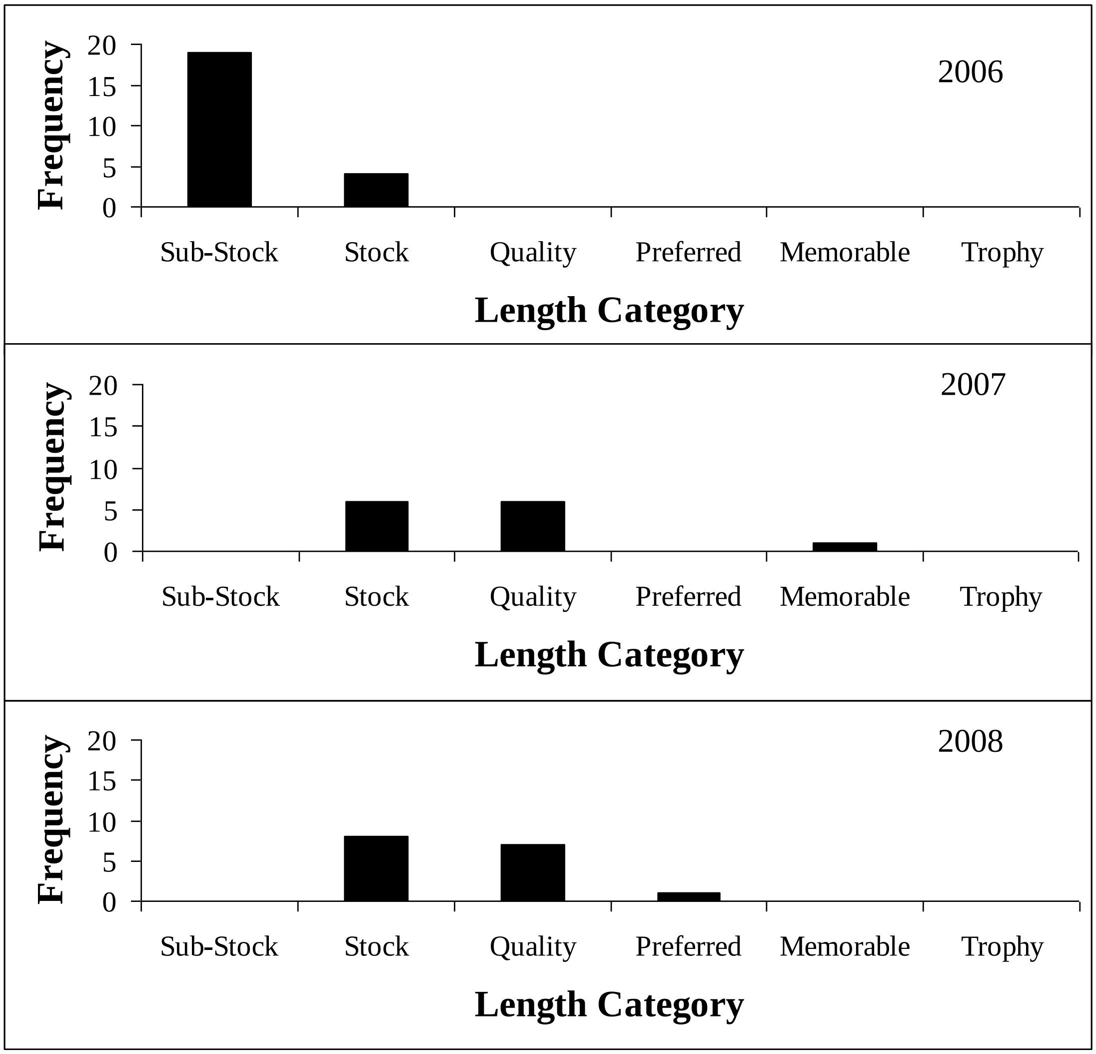

Figure 20. Channel catfish length-category distributions. Gablehouse length-category distributions of gill-netted channel catfish in November 2006, November 2007, and June 2008 in La Juventud Reservoir, Nuevo Leon, Mexico.

memorable-length (710 mm TL) channel catfish was captured; those remaining were less than preferred-length (610 mm TL). Catfish length-frequency did not differ between 2007 and 2008 in location ($D = 0.274$; $P > 0.10$) or shape ($D = 0.274$; $P > 0.10$). In 2008 only one preferred-length channel catfish was captured, those remaining were of stock- (280 mm TL) and quality-length. Between 2006 and 2008 (Figure 19) catfish length differed in location ($D = 0.826$; $P < 0.01$), but not in shape ($D = 0.258$; $P > 0.10$).

Age structure

Age ranges estimated from counts of annuli in otoliths varied among years, from ages 0-2 (2006), to ages 0-4 (2007), to ages 2-6 (2008). Furthermore, across consecutive years frequency of age-0 and age-1 gill-netted channel catfish decreased as the number of age-3 and older channel catfish increased (Figure 21).

Growth

Plotting mean length at age-3 for channel catfish collected in 2006, 2007, and 2008 in La Juventud, indicated fish were longer than the mean of means for length-at-age of fish from Louisiana, New Mexico, and Tennessee, and more similar to fish from central Texas ponds (Figure 22).

The von Bertalanffy growth equation could not be applied in 2006 to the mean length-at-age data for channel catfish, due to the small number of age 4 and older fish. No solution was found for iterative linear regression using the von Bertalanffy equation

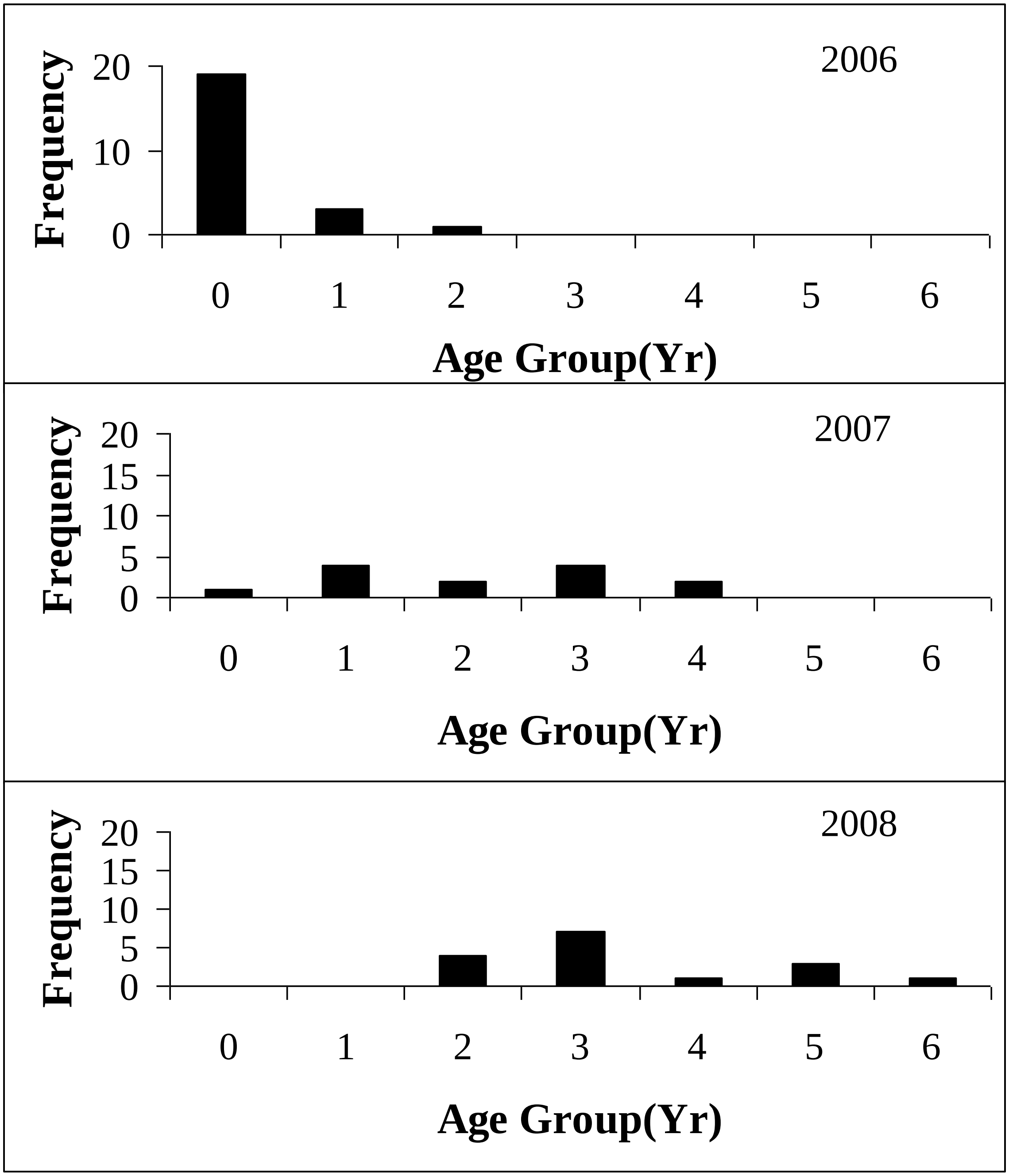

Figure 21. Channel catfish age structure. Age-frequency distribution for gill-netted channel catfish in November 2006 , November 2007, and June 2008 in La Juventud Reservoir, Nuevo Leon, Mexico.

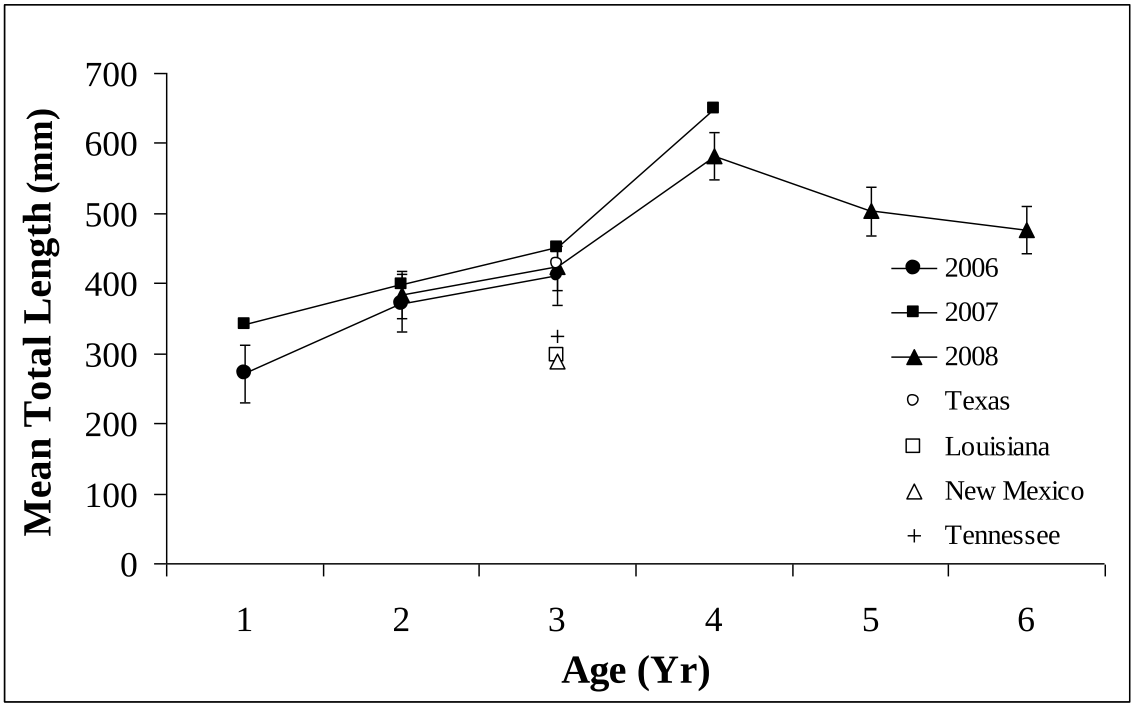

Figure 22. Channel catfish length-at-age evaluations. Mean length-at-age of channel catfish collected in La Juventud Reservoir in 2006, 2007, and 2008, as compared to channel catfish from central Texas ponds, and state-wide in Louisiana, New Mexico, and Tennessee.

parameters when it was applied to the 2007 mean length-at-age data. Only for 2008 data were parameters able to be calculated for L_∞ (659-mm TL), k (0.131) and t_0 (-4.792).

Mortality

The interval mortality rate (A) estimated from pooled (2006-2008 electrofishing and gill netting) catch-at-age data (Figure 23) was 24% (N = 52 ; df = 1 ; $P < 0.05$).

DISCUSSION

Water Quality

I observed no evidence of thermal stratification among the 1-m temperature profile data; based on latitude and water depth, La Juventud is similar to the description of Lewis (Lewis 1983) for a continuously warm, polymictic lake that stratifies at most for only a few hours at a time. Given the agricultural nature of the local watershed and turbidity in La Juventud, oxygen stratification caused by reduced light availability and organic matter decomposition at greater depths may commonly result in oxygen depletion in the hypolimnion (Bouvy et al. 2003; Smith and Smith 2001). La Juventud received little to no rainfall between December 2007 and June 2008 (personal communication, Juan-Antonio Vidalez, UANL Faculty), and as a result, water levels fell several meters. Relatively high conductivity values in June 2008 may be attributed to reduction in reservoir storage volume and subsequent concentration of dissolved nutrients and ions that often occurs during drought conditions (Bouvy et al. 2003).

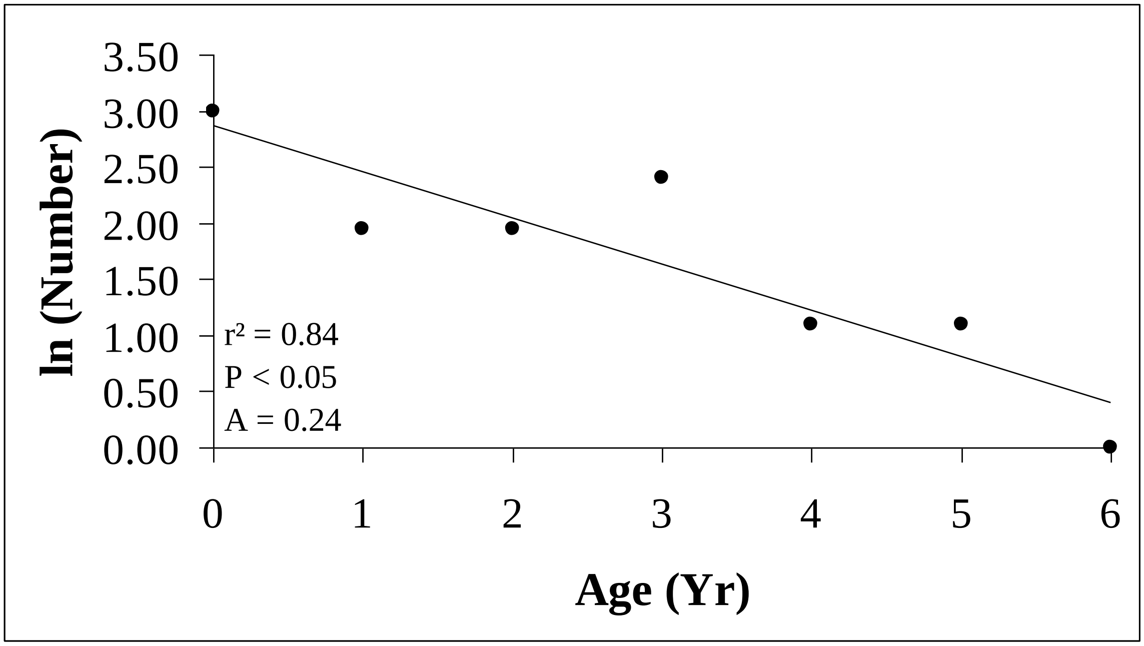

Figure 23. Catch-at-age data for channel catfish. Linearized catch curves collected by gill-net in November 2006, November 2007, and June 2008 at La Juventud Reservoir, Nuevo Leon, Mexico.

Size Structure

Largemouth bass

Although electrofishing is an efficient method of capturing largemouth bass (Reynolds and Babb 1978), lake-bed morphology, season, time of day, and turbidity can influence capture efficiency and size-structure of fish collected. Electrofishing efficiency increases with fish size and a common trend is toward collecting larger fish as compared to collections in similar locations using other gears (Reynolds 1996; Tate et al. 2003). Moreover, size-structure differences among seasons have been documented, with larger size-structures in fall and spring samples, and smaller size-structures in winter and summer (Reynolds and Simpson 1978).

No differences were observed between the size structures of largemouth bass collected during night and day-time electrofishing surveys in 2006 at La Juventud and Dumont (1997) has suggested that differences between day and night electrofishing merge at lower water transparencies, allowing managers responsible for turbid reservoirs more flexibility in diel schedules for monitoring. Electrofishing surveys conducted during the fall have also demonstrated that catch rates are higher at night than during the day and higher for larger individuals when water transparencies are low (Dumont 1997; Kirkland 1965).

Pooled (2006-2007) size structures for largemouth bass collected at La Juventud displayed a regular decline in frequency with increasing length, especially when length-frequency distributions were restricted to fish larger than stock size (e.g., largemouth bass ≥ 200 mm TL; Figure 6). In addition, a common feature among electrofishing length frequency distributions was the near absence of largemouth bass greater than or equal to 340-mm TL. A length-frequency distribution from a balanced fish population should have a regular pattern of decline toward longer fish, but also assumes a stable age structure produced by consistent recruitment and growth, and moderate rates of mortality among age-classes (Neumann and Allen 2007). Neumann and Allen (2007) also suggested that size structures with few individuals in quality- to trophy-length (≥ 300 mm) categories could indicate populations experiencing slow growth and high mortality rates. Gerhardt and Hubert (1991) demonstrated how exploitation could reduce or eliminate fish in preferred (≥ 380 mm) and memorable (≥ 420 mm) length classes.

Only the 2007 electrofishing PSD (42) was within the generally accepted range (40-70) for a balanced largemouth bass population (Willis et al. 1993); even then, it was closer to the lower threshold. A balanced population has a structure that is intermediate between the extremes of a large number of small fish and a small number of large fish and can sustain a quality fishery because both adequate numbers of catchable-size fish and sufficient numbers of smaller fish are produced to replace those harvested (Ney 1999; Willis et al. 1993). Low PSD has been correlated with moderate to high mortality, slow growth, high density (of intermediate sized fish), and reduced condition for largemouth bass (Guy Christopher and Willis 1990; Wedge and Anderson 1978; Willis et al. 1993). Moreover, negative correlations between PSD and density are even more likely in smaller bodies of water with simple communities (Neumann and Allen 2007). The size structure at La Juventud, with few individuals ≥ 300-mm TL and few to no largemouth bass ≥ 380-mm TL is similar to that in other studies of small impoundments that had high densities of intermediate size largemouth bass (Gablehouse 1984a; Gablehouse 1984b); however, electrofishing catch rates of fish ≥ 200-mm TL (23-35/h; Table 4) were not indicative of high densities .

Capture efficiencies of passive gears are related to fish activity (Hubert 1996) and although largemouth bass exhibit crepuscular peaks in feeding behavior, studies of centrarchid diel activity levels have shown that both adult and juvenile largemouth bass are more active during the day than at night (Demers et al. 1996; Shoup et al. 2004). Nevertheless, only the pooled (2006-2008) length frequency distribution for largemouth bass collected by gill-netting (the majority of which occurred during the day) had an adequate sample size for analysis of size-structure; perhaps because gill net sample periods rarely lasted longer than 6 hours and did not encompass either dusk or dawn.

Gill net length frequencies declined for longer fish, and few exceeded 340-mm TL, further indicating that the largemouth bass population at La Juventud may be experiencing slow growth and high mortality rates. Turbid conditions in La Juventud also should have improved the relative capture efficiency of larger fish, presumably because low light levels reduce reactive distance of visually oriented species, and because more cautious, larger and older fish are captured more easily under low-light conditions (Pope et al. 1975). In addition, it is well noted that large fish are more easily captured in gill nets (Hubert 1996), and the size structures of most fish species collected with experimental gill nets are often overestimated (Pope and Willis 1996). In a study of passive gear selectivity in Lake Nasworthy, Texas, gill nets were not suited to estimate relative abundance due to the differential vulnerability among species; however, they were the best single gear to catch large individuals of several species including largemouth bass (Yeh 1977). Moreover, the absence of largemouth bass < 190-mm TL and the near absence of individuals > 340-mm TL in gill net collections from La Juventud may reflect the bell-shaped size-selectivity of gill nets which causes catch frequency to decline to zero at both ends of a length range (Pope et al. 1975); however, the modes (optimal length captured) and widths (range of lengths captured) of gill net selectivity curves depend on mesh size (Jensen 1986; Pope et al. 1975) and use of experimental nets with several different mesh sizes, each with their own bell shaped selectivity curves, could potentially sample a wide range of sizes including larger individuals.

No differences were observed when pooled length frequency distributions of largemouth bass greater than stock length (≥ 200-mm TL) were compared between electrofishing and gill net collections. Had larger individuals been collected by gill-netting than by electrofishing, the near absence of larger fish > 340-mm TL in the electrofishing samples could possibly have been explained as their more likely presence offshore (in gill nets) than inshore (in electrofishing collections). Consistencies in size distributions however, support the aforementioned predictions of slow growth and high mortality rates for largemouth bass.

Proportional stock density values for 2008 gill net collections were less than 40, which is below the generally accepted stock-density index range (40-70) for a balanced largemouth bass population (Willis et al. 1993). These PSD values are consistent with those determined for electrofishing samples and similarly indicate high mortality, slow growth, and reduced condition (Guy Christopher and Willis 1990; Wedge and Anderson 1978; Willis et al. 1993). The differences in PSD between 2006 and 2007 (fall) electrofishing and 2008 (summer) gill-net samples could possibly be related to seasonal differences in habitat use. Larger individuals move shoreward in the fall as shallow waters cool down after summer maxima, and move offshore to deeper, cooler water in the summer, as shallow waters become uncomfortably warm (Reynolds and Simpson 1978).

Channel catfish

Capture efficiencies of passive gears have been related to fish activity (Hubert 1996) and the day-time gill net collections in 2006 and 2007 may have under sampled channel catfish, which are generally more active between dusk and dawn (Wellborn 1988). Concurrently, the variability observed across 2006, 2007, and 2008 length frequencies could have been caused by small sample size rather than variable recruitment; although, an analysis of age-frequency distribution among years would be necessary to test this possibility. Nevertheless, only two channel catfish greater than preferred-length (610-mm TL) were captured across all samples. Perhaps few channel catfish exceeded quality length (410-mm TL) in La Juventud because of high mortality rates and slow growth. Gerhardt and Hubert (1991) demonstrated how exploitation in a channel catfish fishery could reduce or eliminate fish in preferred- and memorable-length size classes, and Schrader (2003) found that the production of large channel catfish in Brownlee Reservoir, Oregon was limited by slow growth and natural mortality.

Shoreline Seining and Electrofishing CPUE

Shoreline seining is a technique commonly used for assessing species composition, presence, and reproductive success; especially of bluegill and largemouth bass collected in spring and summer (Conley et al. 2004; Reynolds and Simpson 1978). Few largemouth bass (≤ 150 and > 150-mm TL), bluegill, and blue tilapia (≤ 80 and > 80-mm TL) were collected in June seine hauls, which may indicate poor reproductive success or low survival of young fish. However, good numbers of age-0 largemouth bass were present in November electrofishing collections of that same year indicated that reproduction was fairly successful. Pine (2000) noted that seining was less efficient than other sampling methods at capturing largemouth bass > 80-mm TL. At sub-tropical and tropical latitudes, evidence suggests that the largemouth bass spawning season begins as early as January (Clugston 1966; Waters and Noble 2004), possibly allowing age-0 individuals to grow to sizes that are less efficiently sampled by seining later in the spawning season. Furthermore, the presence of age-0 largemouth bass collected in November electrofishing surveys could potentially be explained by spawning events that occurred after June; multiple spawning events throughout the spawning season have been reported at lower latitudes (Dadzie and Aloo 1990; Waters and Noble 2004). Discrepancies between young-of-year largemouth bass collected by seining and electrofishing may also be due to the known size-related disadvantages of seining (Higginbotham 1997).

In summer 2008, reservoir staff indicated that La Juventud had received little to no rainfall since December of 2007 (personal communication, Juan-Antonio Vidalez, UANL Faculty) and consequently, water levels had fallen significantly, exposing much of the previously inundated physical habitat structure along both reservoir and creek shorelines. Among species of recreational interest, seine contents at that time were composed mainly of recently hatched (<80 mm TL) and intermediate size (80 mm TL) bluegill and blue tilapia. Few to no young-of-year (≤150-mm TL) largemouth bass were captured in 2008 seine hauls, suggesting poor reproductive success and survival of young fish. Largemouth bass prefer hard substrate to soft clay and mud as spawning sites (Davis and Lock 1997); the drastic fall in water level before or during spawning season may have decreased the amount of preferred upper-reservoir spawning substrate. Moreover, the loss of littoral-zone physical structure that provides refuge for young fish from predation could have been an important influence that year on recruitment of young largemouth bass (Dibble et al. 1996; Havens et al. 2005). Spawning and refuge habitat along the shoreline of La Juventud was no longer inundated by mid-June when sampling took place, and thus, might have contributed to low CPUE of young largemouth bass in seine hauls. Lower water levels may also have concentrated recently hatched bluegill and blue tilapia which may explain the higher abundances of these fish in seine haul catches.

The presence of recently hatched tilapia in seine hauls suggests that blue tilapia also had successfully reproduced. Reproductively mature blue tilapia can compete with largemouth bass for nesting sites (Noble et al. 1975) and may have contributed to the near absence of recently hatched largemouth bass in seine hauls. Furthermore, competition is more likely under conditions of limited resource availability (Krebs 2001; Pianka 1974), and in La Juventud, the lower water levels and reduction in availability of upper-reservoir spawning substrate may have induced competition among these two nest-spawning species during overlapping spawning periods. Other undesirable interactions that may have contributed to the near absence of young-of-the-year largemouth bass in 2008 seine hauls can also include predation on largemouth bass eggs and fry by abundant bluegill (Bickerstaff and Ziebell 1984; Carlander 1969; Higginbotham 1988) and juvenile blue tilapia (Pompa and Masser 1999). Non-native tilapia species are found in every state in Mexico and are established in the wild across much of the country due to introductions from privately sponsored imports as well as state and federal fisheries programs in the 1960s and 1970s that were aimed at increasing the protein content of the diets of rural people, and established them as premier among cultured fish (Fitzsimmons 2000). The adverse influence of blue tilapia on the success of largemouth bass spawning is a factor that managers of largemouth bass fisheries may likely have to consider for intensive management efforts.

Larval growth and survival of largemouth bass may also have been negatively affected by competition with planktivorous shad species (Aday et al. 2003;

Higginbotham 1988), which were relatively less abundant in 2007 (CPUE = 1.23) than in 2008 (CPUE = 9.96).

Age-Structure and Recruitment

Largemouth bass

Maceina and Pereira (2007) suggested that in a single sample of fish representing a number of cohorts or year-classes, highly variable recruitment will cause the relation between age and number-at-age to vary. Year class formation appeared relatively weaker in 2007 and the number of age-2 fish declined between years; however, these differences may just have been due to a smaller sample size.

Largemouth bass samples collected at La Juventud were dominated by young age classes (0-4) and a trend towards near absence of older individuals was common among electrofishing samples. Only one individual from each of age groups 5, 6, and 7 were captured, and the population did not approach the maximum potential longevity (24 years) of the species (Green and Heidinger 1994). Fisheries generally operate by removal of large and old individuals through size-selective fishing mortality that can effectively truncate the size and age structure of a population (Hsieh et al. 2006). Furthermore, age distributions consisting of mostly young and few old individuals are characteristic of samples with PSD values below the optimal range (Reynolds and Babb 1978).

The collection of only a few age-0 largemouth bass by gill-netting more than likely reflects size-selective properties of the sampling gear, which is known to be less efficient in collecting smaller and younger fish (Hubert 1996). Age-specific behavior of older and rarer largemouth bass often require greater sampling effort to capture representative numbers of individuals (Bettoli and Miranda 2001; Maceina and Pereira 2007) and the near absence of older individuals in age-structure histograms can often be attributed to insufficient sampling effort (Bettoli and Miranda 2001). However, considering the small size of La Juventud, the total efforts of electrofishing and gillnetting samples, and the similarities of age structures between samples collected with the two gears, it is unlikely that an insufficient effort was the reason for few older and larger fish in the sample.

Channel catfish

The maximum age of channel catfish determined from otolith annuli counts at La Juventud was 6-years old; although channel catfish of 21 – 23 years old have been captured throughout the United States, the most frequently observed maximum is 8-years old (Hubert 1999). Assuming that gill netting effort was sufficient enough to ensure that cohorts of year classes were thoroughly represented; the variability among number-at-age and age in 2006, 2007, and 2008 samples of channel catfish collected at La Juventud could possibly be attributed to erratic recruitment (Maceina and Pereira 2007). La Juventud does not have an annual channel catfish stocking program and fingerling (100-mm TL) stocking rates vary based on feedback from anglers and recommendations by reservoir biologists (personal communication, Sergio Gonzalez, UANL Faculty). Stocking age-0 fish can cause age-frequency histograms to vary with rates, sizes, and frequencies of stocking (Miranda and Bettoli 2007).

Predatory species such as largemouth bass are known to remove a significant proportion of the channel catfish reproduction in small impoundments (Conley et al. 2004). Moreover, the impacts of a regularly over-wintering double-crested cormorant population in La Juventud may also contribute to the observed variability in the distribution of number-at-age. Based on their numbers and fishing abilities, cormorants are a perceived threat to aquaculture and to a lesser extent recreational fishing. Studies to estimate the food habits and impact of double-crested cormorants on catfish populations in the Mississippi Delta have determined that 100 - 200-mm TL catfish were preyed upon most often and a diet shift towards more catfish occurs leading up to the time of cormorant migration (Brugger 1995; Glahn and Brugger 1995; Sutter 1995).

Fluctuating water levels associated with variable precipitation and a drought prone climate can also reduce reproduction by decreasing the amount of suitable reservoir spawning habitat preferred by channel catfish (Schrader et al. 2003) in the form of rubble, boulders, and cavities (Hubert 1999; Wellborn 1988) along the shoreline of the dam and upstream in Salidito creek.

Growth

Largemouth bass

Based on data collected from reservoirs and ponds throughout the United States, Carlander (1977) considered growth adequate if largemouth bass reached a total length of 4 inches (10 cm) at age-1; 8 inches (20 cm) at age-2; and 10 inches (25 cm) at age-3. In addition, data from small impoundments in the central U.S. (Reynolds and Babb (1978) suggested that a balanced population of largemouth bass has a growth rate that permits 8-inch (200-mm TL) individuals to reach 12-inches (300-mm TL) within approximately 1 year. By comparison, largemouth bass at La Juventud reached and surpassed stock size (200-mm TL) by age-1 and quality size (300-mm TL) by age-3. Conversely, growth of individuals older than age-3 appeared stagnant and may be indicative of a stunted population; 5 and 7 year old fish from electrofishing and gill net collections had reached 392- and 367-mm TL, (respectively) in La Juventud; not much larger than the mean length for age-3 largemouth bass. Furthermore, the L_∞ for largemouth bass at La Juventud was relatively smaller than that of Florida populations even though growth coefficients were similar between regions, which also suggests that the growth potential is limited at La Juventud reservoir.

Mean length-at-age-1 values of largemouth bass from La Juventud were relatively larger than those of populations from the Southeastern U.S.A. An early onset of spawning and extended length of the growing season at lower latitudes may provide one possible explanation for such results. Optimal spawning temperatures are reached relatively early in the year in tropical and sub-tropical regions, such that the spawning season can begin as early as January (Clugston 1966; Neal and Noble 2002; Waters and Noble 2004). If similar conditions apply to sub-tropical regions such as Northeastern Mexico then individuals spawned earlier in La Juventud should experience a longer first-growing season and attain a larger size by their first winter (Conover 1992). Early spawned fish may also be able to exploit an abundant source of forage species that spawn later in the spring and through the summer (e.g., threadfin shad, bluegill, and blue tilapia) throughout most of their first growing season, further maximizing their growth rates (Shelton et al. 1979). In an Alabama reservoir, young of largemouth bass that had spawned significantly earlier than threadfin shad were able to prey on shad throughout their entire first year and to attain a growth advantage over later-hatched individuals (Sammons et al. 1999).

The growth coefficient (k) estimated for largemouth bass at La Juventud was not as large as the k value reported for Lucchetti Reservoir in Puerto Rico (Ozen and Nobel 2000); however, growth of older largemouth bass (> age-3) and the L_{∞} estimated for fish in La Juventud were similar to the growth and L_{∞} of largemouth bass in Lucchetti reservoir (Neal and Noble 2002). Neal and Noble (2006) examined the relationship between latitude and maximum size of largemouth bass in sub-tropical and tropical environments using a bioenergetics approach, and indicated that extended spawning effort at lower latitudes, where the reproductive period can last several months, could increase energy demands that would otherwise be allocated to growth, thereby limiting growth capacity and contributing to accelerated mortality. If such conditions exist in La Juventud, and are common throughout Northeastern Mexico, then the feasibility of trophy and tournament fishing in the region may be limited without specific management intervention.

Channel catfish

Channel catfish mean length-at-age values were similar to the mean of means for length-at-age values of fish in Texas, and larger than the mean values from several regions in the Southern U.S.A. (Hubert 1999). In addition, stock size (280-mm TL) and quality sizes (410-mm TL) were reached in less than one and four years (respectively). Channel catfish grow best in warm water environments with optimum growth occurring at 29°C. The onset of channel catfish spawning is closely associated with temperatures greater than or equal to 21°C (Hubert 1999), and has been observed as early as February (Wellborn 1988). If optimal temperatures are reached early in the breeding season in La Juventud then channel catfish that are spawned early could experience a longer season for initial growth (Conover 1992) than individuals spawned at higher latitudes, and thus, may attain a growth advantage early in life.

La Juventud does not have an annual channel catfish stocking program (personal communication, Sergio Gonzalez, UANL Faculty); relatively fast growth rates could be the result of low intraspecific competition among lower densities of channel catfish because reservoirs with infrequent stocking rates are less likely to have self-sustaining populations of channel catfish due to removal of a large portion of potential recruits by predatory species such as largemouth bass (Michaletz 2006; Society 2004).

Mortality

Largemouth bass

Instantaneous mortality rates (Z) can vary from 0 to slightly over 4, which corresponds to interval mortality rates (A) between 0 and 100% (Miranda and Bettoli 2007). The A estimated from pooled catch-at-age data collected by electrofishing across years 2006-2007 was 53% (N = 101) whereas A estimated from pooled catch-at-age data collected by gill-netting across years 2006-2008 was 20% (N = 72). The catch curve for the gill-net data was highly uneven and the linear regression used to estimate mortality Rates from pooled catch-at-age data for gill-netted fish was not statistically significant so as a result of the uncertainty associated with this estimate, more confidence should be placed in the annual mortality rate estimated from electrofishing data. Based on comparisons between steady-state models and pond censuses, Reynolds and Babb (1978) found that balanced largemouth bass populations with moderate annual mortality had values of A ≤ 50% for ages 2-4. Furthermore, when compared to a range of total morality rates for populations in the U.S.A., the interval mortality rates estimated for largemouth bass in La Juventud were moderately high (Beamesderfer 1995; Allen 1998). Separation of fishing and natural mortality in La Juventud was not possible with the data available; however, in a review of several total mortality and exploitation estimates for largemouth bass populations across the U.S.A. Allen (1998) documented that total mortality increased with increased exploitation, as would be expected if annual mortality and annual exploitation were additive or only partially compensatory. Correlations among high mortality, low PSD, and slow growth of older individuals are well established in the literature and are consistent with the parameters and conditions observed for La Juventud (Gablehouse 1984a; Gablehouse 1984b; Guy and Willis 1990; Willis et al. 1993). Moreover, fishing mortality is higher for older individuals (Miranda and Bettoli (2007) and in order to preserve a desirable PSD, lower mortality is required, especially for slow-growing populations (Miranda 2002).

Biologists at La Juventud have also expressed concern that predation from over-wintering cormorants may be contributing to mortality of larger individuals (personal communication, Sergio Rodriguez, UANL Biologists). A total of only four largemouth bass with injuries from cormorant attacks were observed in samples; all individuals were approximately between 250- and 260-mm TL.

Channel catfish

In a survey of catfish management in the U. S. A. and Canada, Michaletz and Dillard (1999) found that effective sampling methods for catfishes remain elusive, especially in small impoundments and reservoirs where catches are often low and variable. As a result of such sampling constraints, parameters such as mortality are often difficult to determine because in order to reduce error in mortality estimates large sample sizes among age groups are required (Miranda and Bettoli 2007), but when gill net sample sizes were small, pooling several years of data was required to produce sample sizes large enough for mortality estimation. Considering the possible annual mortality range of 0-100%, interval mortality rate (A) in La Juventud estimated from catch-at-age data collected by gill netting pooled across years 2006-2008 was moderately low (24%), but survival (76%) was within the range reported in other North American systems (Hubert 1999; Schrader et al. 2003). Neumann and Allen (2007) have suggested that size structures with few individuals in the range of quality- to trophy-length categories could indicate that channel catfish populations are experiencing slow growth and high mortality rates; however, in my samples, channel catfish growth and mortality rates deviated from those expected based on the observed size structure, which appeared truncated, with few fish larger than 410-mm TL (quality size). These contradictions may reflect estimation error of channel catfish mortality resulting from a small sample size, inadequate sampling methods, or variable recruitment; however, the linearized catch curve did not show any indication of partial recruitment to the gear (i.e. inefficient capture) among any age groups. Due to the difficulty in determining age-structures, growth rates, and mortality estimates of channel catfish, Michaletz and Dillard (1999) determined that size-structures were considered more useful in assessment of their population dynamics. Hubert (1999) reiterated that difficulties associated with deriving sound estimates of annual total mortality and exploitation rates for channel catfish were due to abundances required for representative samples, accurate aging, and unmet assumptions of constant recruitment among years.

Minimum Length Limit Evaluations

Largemouth bass

Fish populations of small impoundments are particularly susceptible to harvest, but small size, coupled with control over access, makes privately-owned ponds conducive to management with size-limit regulations (Funk and Anderson 1974).

Variability in recruitment of largemouth bass caused by a drought-prone environment and undesirable interactions with other nest-spawning species (bluegill, and blue tilapia), fast growth to quality size (300 – 379 mm TL), and high mortality rates suggest the need for minimum-length limits, which should allow UANL biologists to sustain a quality-size largemouth bass fishery at La Juventud. Such regulations for many Tennessee Wildlife Resource Agency fishing lakes are successfully managed to provide large numbers of quality sized largemouth bass (Churchill and Reeves 1999). Minimum-length limits have their greatest impact in reservoirs where recruitment rates are lower and more variable, growth is moderate to fast, and fishing mortality is moderate to high. Size limits also can maintain favorable fish populations and community structure, and quality fishing, by lowering both angling and total mortality, and reducing exploitation of fish before they reach sexual maturity (Noble and Jones 1999). Based on the response of largemouth bass mortality rates to exploitation, Allen (1998) suggested that total mortality of largemouth bass is additive and can be reduced through harvest restrictions. Conservative bag limits for largemouth bass and the 600-mm TL limit currently in effect at La Juventud probably reflect management objectives aimed at limiting exploitation and creating a trophy fishery with the potential for anglers to catch large fish. However, it is evident from the sizes of largemouth bass collected in my electrofishing and gill net surveys, and mean length-at-age evaluations in which growth appears to slow considerably after age-3, that a 600-mm TL minimum length limit would not provide satisfactory levels of angler yield and harvest, but rather would limit anglers to catch-and release only. Dissatisfaction among anglers who wish to harvest fish may lead to non-compliance with fishing regulations and illegal harvest of sub-legal-size fish, which may contribute to the largemouth bass size structure observed at La Juventud, where few fish exceed 340-mm TL. Moreover, if the three-fold increase in fishing days observed at La Juventud indicates high exploitation rates, and if anglers are harvesting fish below the minimum-length limit, then the near absence of largemouth bass longer than 340-mm TL could also reflect the minimum length at which fish become desirable for harvest by most anglers at La Juventud.

Integration of von Bertalanffy and weight:length functions with FAST software allowed for several minimum-length limit options, reflecting a range for growth of the largemouth bass at La Juventud to be simulated. At a conditional natural mortality rate of 20%, yield (kg) declined with the 200-mm TL limit at exploitation rates greater than 30%, more than likely due to growth over fishing, a condition in which fish are removed from the population at such a fast rate and early age that maximum growth potential and yield (kg) are not reached (Slipke and Maceina 2001). Moreover, yield (kg) was higher for the 300-mm TL limit at lower exploitation rates, but higher with the 380-mm TL length limit at higher exploitation rates. At a conditional natural mortality rate of 40%, yields predicted for the 380-mm TL limit did not surpass those predicted by the 300-mm TL limit, more than likely because fish died before they recruited to the higher size limit.

For all conditional natural mortality rates simulated, the number of fish harvested was greater at lower minimum-length limits. Considering the observed growth conditions, high annual mortality, and the uncertainty of estimates for natural and fishing mortality rates at La Juventud, a minimum-length limit between 300- and 380-mm TL is prudent. A minimum-length limit closer to 300-mm TL should provide anglers with a higher yield (kg) and number harvested, but mean size and mean weight of fish harvested would be smaller than with a minimum-length limit closer to 380-mm TL; thus, a tradeoff exists between quantity (number of fish harvested) and quality (size of fish harvested). The Texas Parks and Wildlife Department uses a minimum-length limit of 14 inches (356-mm TL) for harvest of largemouth bass in reservoirs across the state.

Channel catfish

Michaletz and Dillard (1999) indicated that creel limits have been commonly used among fishery management agencies to manage channel catfish populations, although size limits have experienced a nine-fold increase in use since the 1980's. The restricted bag limit and minimum length limit of 350-mm TL currently in effect at La Juventud probably reflects management objectives aimed at limiting exploitation and increasing angler yield (kg); however, channel catfish generally mature at 300-350-mm TL (Hubert 1999) and this size limit may not allow a significant proportion of the fish to become sexually mature and spawn before becoming vulnerable to harvest. In a put-and–take, or put-grow-and-take fishery where fingerlings are stocked frequently this would not be problematic; however, considering the infrequent stocking rates at La Juventud and the potential for largemouth bass predation to remove a significant proportion of the natural channel catfish reproduction (Conley et al. 2004), higher minimum-length limits may be necessary to sustain fishing quality and angler yield, and to protect the fishery from growth over harvest.

CHAPTER III

FEEDING HABITS, CONDITION INDICES, AND PREY AVAILABILITY

INTRODUCTION

Population dynamic analyses were supplemented by a multi-pronged analysis of feeding habits, fish condition, and prey-availability at La Juventud in order to approximate the extent to which growth, mortality, and recruitment may be influenced by length-related patterns in feeding habits and predator-prey interactions.

METHODS

Stomach Content Examination

Stomachs (muscular organ from the esophagus to the anterior portion of the intestine, i.e., the true stomach) were dissected so that they could be examined and evaluated for fullness, removal of all prey, and morphology of trophic structures (Gelwick and Matthews 1996). The stomach contents of largemouth bass and channel catfish were examined using a dissecting microscope (from 0.80X to 4.0X), and prey items were identified to family and genus levels; diagnostic characteristics of digestion-resistant hard structures (scales, bones, exoskeletons) were used to identify fragmented and partially-digested prey items. Presence or absence of food items was recorded to calculate a frequency-of-occurrence index (the proportion of all stomachs with food that contained a particular food item). Frequency of occurrence (FO) was used to evaluate how often a particular prey type was eaten and to indicate the extent to which fish in samples functioned as a singular feeding unit (Bowen 1996; Chipps and Garvey 2007; Gelwick and Matthews 1996). Samples were stratified by Gablehouse fish-length categories because fish size can affect both the quantity and composition of items within diets, and hence, pooling data across strata could poorly reflect the actual distribution of individual diets within samples (Bettoli and Miranda 2001; Bowen 1996; Chipps and Garvey 2007). Results from 2006, 2007, and 2008 diet analyses are presented as tables in order to evaluate prey frequency and predator influences within the reservoir. There was no evidence of regurgitated prey in the samples, but a large portion of fish from the 2006 electrofishing and gill net samples had empty stomachs. This is assumed to have been related to not only feeding periodicity, but also reactivation of digestive processes when frozen fish thawed during a weekend (two-day) power outage in Spring 2007.

Weight

Relative weight (Wr) values are used to evaluate the physiological well being of fish (Anderson and Neumann 1996; Pope and Kruse 2007). Relative weight (Wr) indices are calculated by comparing fish weight when captured to a length-specific standard weight (Ws) inferred from a weight-length regression fit to the 75th percentile of weights at species-specific total-length intervals from pooled weight-length data across the species geographical range (Anderson and Neumann 1996; Hillman 1982; Pope and Kruse 2007; Wedge and Anderson 1978). This method was used to calculate Wr for largemouth bass and channel catfish in La Juventud. For some species, pooled weight-length data has been found to be size-biased (Anderson and Neumann 1996) and in such cases Wr indices are calculated by comparison of observed fish weight to a length-specific Ws inferred using the regression-line percentile technique (Brown et al. 1995). This latter method was used for channel catfish in La Juventud. Ratio data, such as Wr, tends to exhibit heteroscedasticity, leptokurtosis, and skewness in its distribution that make assumptions of normality implausible, and thus the use of parametric t-tests and analysis of variance (ANOVA) are inappropriate (Brenden et al. 2003; Pope and Kruse 2007). Because Wr is conditional on fish length, this data also may depart from the assumptions of independence and identical distribution of observations that are critical to both parametric and non-parametric tests (Bolger and Connolly 1989; Brenden et al. 2003). Although the statistical properties of the Wr index have been debated, Pope and Kruse (2007) suggest that parametric and non-parametric mean- and median-comparison techniques can be adequate for testing hypotheses for Wr data, under the provision that limitations of the statistical techniques are known and robust tests are used. In order to determine the appropriateness of parametric and non-parametric tests, descriptive statistics (histograms) and tests of normality (Q-Q plots, Shapiro-Wilks test) were derived.

Prey Availability

To acquire insight into prey availability at La Juventud, the sizes and abundances of the major forage species (bluegill, blue-tilapia, and threadfin shad) were evaluated. The lengths of bluegill and blue tilapia collected by electrofishing and gill-netting in

2006, 2007, and 2008 were apportioned into length-frequency distributions (10-mm TL length intervals). Furthermore, CPUE values of forage species collected in summer (June 2007 and 2008) seine hauls were used to assess the abundance of threadfin shad < 0-mm TL, and bluegill and blue tilapia ≤ 80-mm TL, and > 80-mm TL.

RESULTS

Stomach Content Examination

Largemouth bass

Between 2006 and 2008 a total of 150 largemouth bass stomachs were removed to examine gut contents and determine percent frequency-of-occurrence (FO) of food items (Table 8). Largemouth bass were stratified into Gablehouse length categories so that length-patterns in feeding habits would not be overlooked. Because sample sizes were small (<10) for preferred length groups in 2006, quality and preferred length groups in 2007, and sub-stock, quality, and preferred length groups in 2008, food habits of these length categories may not be properly represented, and caution is used when interpreting FO. The percentage of empty stomachs ranged from 33.3 to 62.1% in 2006, 21.7 to 66.7% in 2007, and 33.3 to 100% in 2008. Except for preferred-length fish, the percentage of empty stomachs was lower in 2007 for most length categories than for the same category in 2006 and 2008. In 2006, largemouth bass of all length categories fed most frequently on fish. Of the fish that could be identified, threadfin shad were observed in the diet of all length categories; however, whereas threadfin FO declined as length group increased, blue tilapia FO increased. Sub-stock largemouth bass fed most frequently on threadfin shad; stock largemouth bass fed most frequently on both threadfin shad and blue tilapia; quality largemouth bass fed most frequently on blue tilapia. In 2007, as the largemouth bass length category increased the FO of aquatic insects declined, while the FO of fish in the diet increased. Sub-stock largemouth bass most frequently contained fish and notonectids, whereas the diet of stock and quality largemouth bass most frequently contained fish; specifically, of the prey fish that could be identified, threadfin shad were most frequently consumed by stock-length individuals. Prey less-frequently utilized by stock length individuals were aquatic insects and crayfish. In 2008, stock-length largemouth bass most frequently fed on unknown fishes, thread fin shad, and notonectids; crayfish were consumed less frequently.

Channel catfish

Between 2006 and 2008 a total of 40 channel catfish stomachs were removed by dissection to examine gut contents and determine FO for food items (Table 9). Sample sizes were not large enough to stratify FO by length group so fishes of all length were combined for food habit analysis by year. In 2006, dipterans, threadfin shad, bluegill, and detritus were observed most commonly in stomach contents; in 2007, fish and crayfish were the most common prey, and detritus was observed less frequently; and in

Table 8. Quantitative description of largemouth bass diet. Stomach contents, represented by percent frequency of occurrence (FO), of 150 largemouth bass collected by electrofishing and gill netting from La Juventud Reservoir in November 2006, November 2007, and June 2008. Percent frequency of occurrence is separated into sub-stock, stock, quality, and preferred Gablehouse length categories to identify length-related patterns in diet.

Stomach contents	Fall 2006				Fall 2007				Summer 2008			
	Sub-Stock	Stock	Quality	Preferred	Sub-Stock	Stock	Quality	Preferred	Sub-Stock	Stock	Quality	Preferred
Food item	FO	FO	FO	FO	FO	FO	FO	FO	FO	FO	FO	FO
Aquatic Insects	0.0	0.0	0.0	0.0	55.6	6.7	0.0	0.0	66.7	26.3	0.0	0.0
Notonectidae	0.0	0.0	0.0	0.0	50.0	6.7	0.0	0.0	66.7	26.3	0.0	0.0
Diptera	0.0	0.0	0.0	0.0	5.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Fishes	100.0	80.0	100.0	100.0	72.3	93.4	100.0	100.0	66.7	83.9	0.0	0.0
Threadfin Shad	33.3	30.0	16.7	0.0	5.6	46.7	0.0	0.0	0.0	31.6	0.0	0.0
Bluegill	0.0	0.00	0.0	100.0	0.0	6.7	0.0	0.0	0.0	0.0	0.0	0.0
Blue Tilapia	0.0	20.0	50.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	0.0	0.0
Unknown	66.7	30.0	33.3	0.0	66.7	40.0	100.0	0.0	66.7	52.3	100.0	0.0
Other	0.0	10.0	0.0	0.0	0.0	13.3	0.0	0.0	33.3	5.3	0.0	0.0
Crayfish	0.0	10.0	0.0	100.0	0.0	13.3	0.0	0.0	0.0	5.3	0.0	0.0
Arachnida	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	33.3	0.0	0.0	0.0
No. of largemouth examined	9	29	16	1	23	21	6	3	3	33	6	1
No. of stomachs with food	6	10	6	1	18	15	4	3	2	19	2	1
% empty stomachs	33.3	62.1	62.5	0.00	21.7	28.6	28.6	66.7	33.3	42.2	66.7	100.0

Table 9. Quantitative description of channel catfish diet. Stomach contents, represented by percent frequency of occurrence (FO) in November 2006, November 2007, and June 2008, for 40 channel catfish collected by electrofishing and gill netting in La Juventud Reservoir.

Stomach contents	2006	2007	2008
	Fall	Fall	Summer
Food item	FO	FO	FO
Aquatic Insects	50.0	0.0	63.5
Notonectidae	0.0	0.0	18.1
Diptera	50.0	0.0	0.0
Chironomidae	0.0	0.0	27.3
Ephemeridae	0.0	0.0	18.2
Fishes	50.0	41.7	45.5
Threadfin Shad	0.0	8.3	9.1
Bluegill	50.0	0.0	0.0
Carp	0.0	0.0	18.2
Unknown	0.0	33.3	18.2
Other	50.0	33.3	100.0
Crayfish	0.0	25.0	0.0
Detritus	50.0	8.3	18.1
Arachnida	0.0	0.0	9.1
Squamata	0.0	0.0	9.1
Hymenoptera	0.0	0.0	27.3
Orthoptera	0.0	0.0	9.1
Coleoptera	0.0	0.0	9.1
Legumes	0.0	0.0	9.1
Corn	0.0	0.0	9.1
No. of channel catfish examined	11	12	17
No. of stomachs with food	3	10	6
% empty stomachs	72.7	16.7	64.7

2008, chironomids, ephemeroptera, carp, unknown fish, and hymenopterans were the most frequent prey, whereas a wide variety of insects, crustaceans, and legumes were observed less frequently.

Condition

Largemouth bass

Except for preferred largemouth bass in 2007, mean W_r values of sub-stock-, stock-, and quality-length individuals collected in 2006, 2007, and 2008 (Figure 24) were below the benchmark range (95-105) for a fish in optimal condition (Anderson and Neumann 1996; Pope and Kruse 2007).

Channel catfish

Due to the small sample sizes of several Gablehouse length categories, only the mean Wr of sub-stock and stock-length channel catfish in 2006, and of stock and quality length channel catfish in 2007 and 2008 were calculated (Figure 25). All means for Wr of sub-stock, stock, and quality channel catfish were below the benchmark range (95-105) for a fish in optimal condition (Anderson and Neumann 1996; Pope and Kruse 2007).

Prey Availability

Population structure

Due to small sample sizes, data for bluegill and blue tilapia were pooled across years (Figure 26) for electrofishing (2006 and 2007), and gill netting (2006, 2007, and

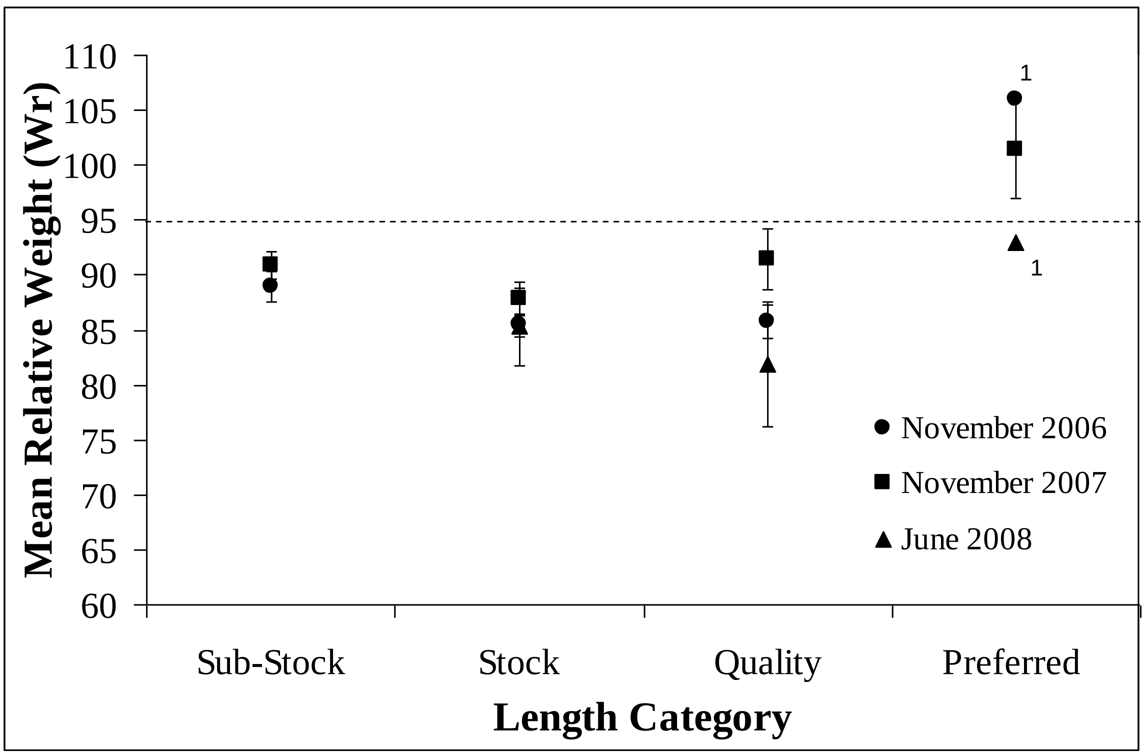

Figure 24. Largemouth bass indices of condition stratified across length categories. Average relative weight values for sub-stock, stock, quality, and preferred length categories of electrofished largemouth bass during November 2006, November 2007, and June 2008 in La Juventud Reservoir. The dashed line represents the lower threshold for the optimal range (95-105) which is commonly used as a benchmark of a fish in good condition.

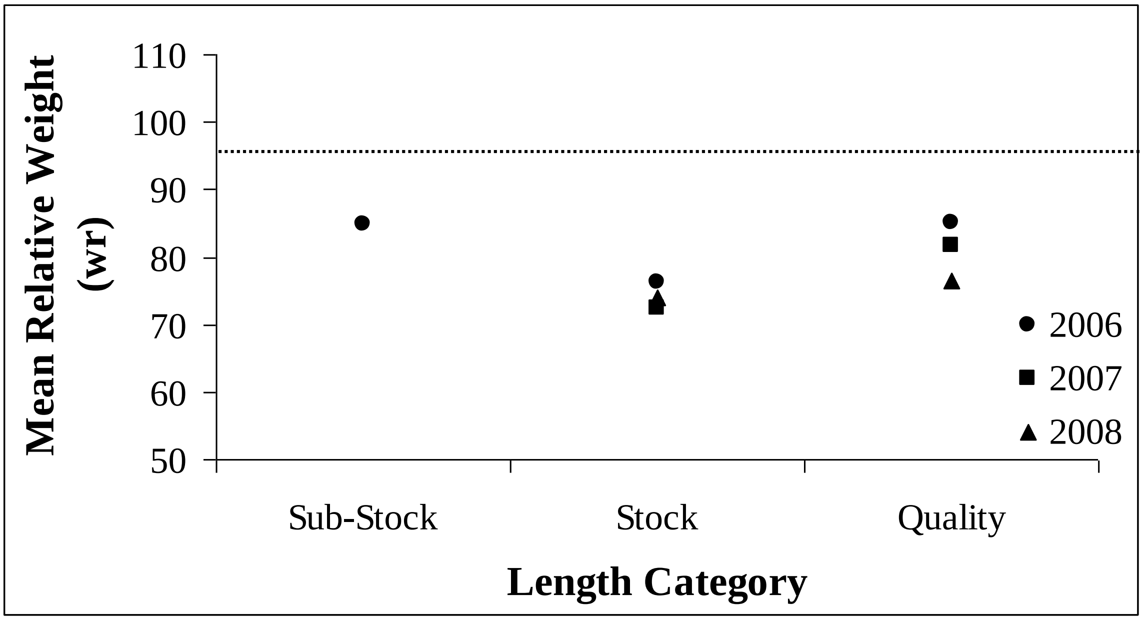

Figure 25. Channel catfish indices of condition stratified across length categories. Average relative weights combined for all lengths of gill-netted channel catfish during November 2006, November 2007, and June 2008 in La Juventud Reservoir. The dashed line represents the lower threshold for the optimal range (95-105) which is commonly used as a benchmark of a fish in good condition.

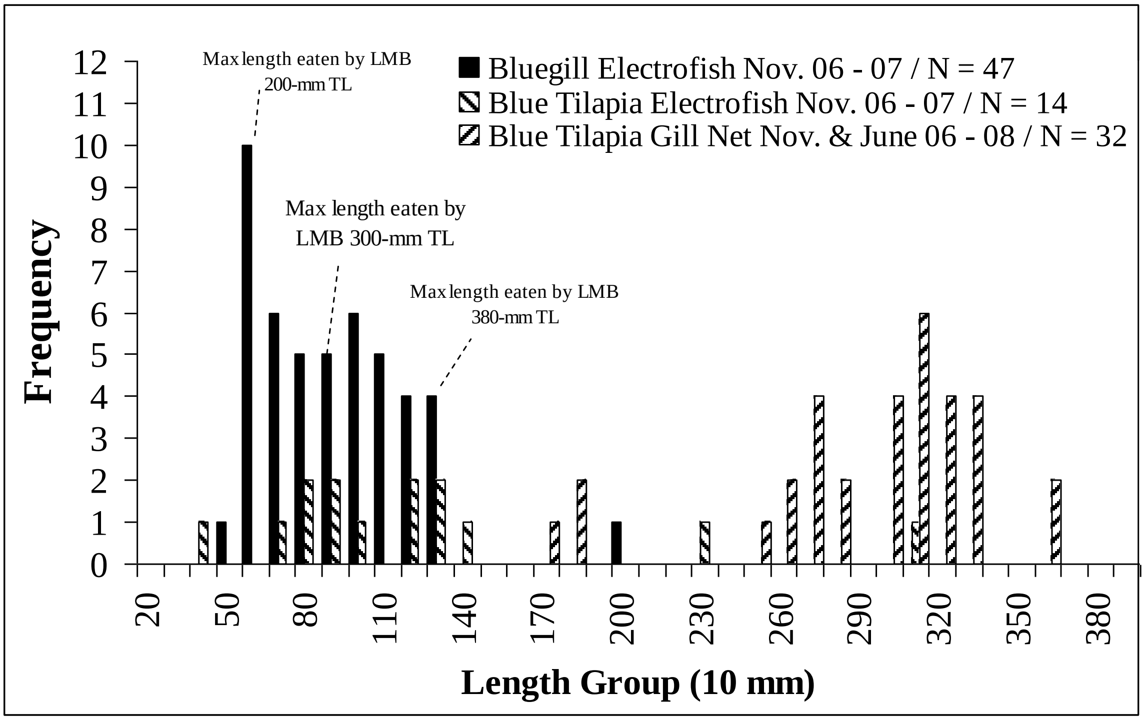

Figure 26. Bluegill and blue tilapia size structure. Length-frequency distributions of electrofished and gill-netted bluegill and blue tilapia pooled across years 2006-2008, in La Juventud Reservoir, Nuevo Leon, Mexico.

2008). The majority of bluegill (N = 47; mean TL = 96 mm, SD = 27.9 mm) and blue tilapia (N = 14; 127-mm TL, SD = 69.0) collected by electrofishing were between the sizes of 40- and 140-mm TL whereas the majority of blue tilapia collected by gill-netting were larger than 250-mm TL (mean TL = 295 mm, SD = 46.0).

Seine haul CPUE

The CPUE of forage fishes collected by seining was highest for threadfin shad in 2007 and 2008, whereas the CPUE of bluegill and blue tilapia were similar in both years. The CPUE of young-of-year sized bluegill and blue tilapia (≤80-mm and > 80-mm TL), and threadfin shad (≤ 60-mm TL) increased between years 2007 and 2008 (Table 10).

Table 10. Relative abundance of forage species in seine haul catches. Catch per unit effort (CPUE) of major forage species collected by seining during June 2007 and 2008 in La Juventud Reservoir, Nuevo Leon, Mexico.

		Bluegill		Blue Tilapia		Threadfin Shad
Year	Total Effort (m^2)	≤ 80 mm	> 80 mm	≤ 80 mm	> 80 mm	≤ 60 mm
2007	360	0.00	0.01	0.01	0.01	1.23
2008	220	2.09	0.11	2.65	0.01	9.96

DISCUSSION

Food Items

Largemouth bass

Except for preferred-length largemouth bass, the percentages of empty stomachs among all length categories were lowest in fall-2007 samples. The percentage of empty stomachs in fall-2006 samples might have been elevated due to a weekend power outage, which could have allowed digestion of freezer-preserved stomachs to resume before power returned, rather than reflecting an actual lower feeding frequencies by larger piscivorous largemouth bass; for summer-2008 collections, empty stomachs may have resulted from regurgitation and post-capture digestion associated with overnight gill-net sampling (Bowen 1996). There was no apparent seasonal trend between summer and fall in the percentage of empty largemouth bass stomachs.

The diet of largemouth bass at La Juventud consisted mostly of aquatic insects, crayfish, and fishes and is consistent with the literature about largemouth bass feeding habits (Carlander 1977; Davis and Lock 1997). Diets also included fewer taxa than reported from other aquatic systems and possibly reflects a simple community in La Juventud (Matthews et al. 1992; Soupir et al. 2000).

Largemouth bass in La Juventud fed primarily on fish, which typically included threadfin shad and blue tilapia. Piscivory in largemouth bass begins when fish reach about 50-mm TL (Carlander 1977; Davis and Lock 1997) and the pattern of decreasing consumption of aquatic insects with increasing fish length is consistent with documented ontogenetic trophic shifts for this species. Of the ingested fishes that were identifiable, threadfin shad were most frequently consumed by largemouth bass in most length categories and throughout all years. Threadfin shad are extremely vulnerable to largemouth bass predation (Conley et al. 2004) and their small, soft-bodied morphology may reduce handling-time energy cost as compared to that for course and deeper-bodied fishes such as bluegill and blue tilapia. The success of prey capture and handling-time energy costs are important tradeoffs that influence prey selectivity (Gill 2003; Savitz and Janssen 1982). Blue tilapia have been suggested as important forage for largemouth bass (Noble et al. 1975; Schramm and Zale 1985), and in La Juventud, an increase in FO of blue tilapia within longer length groups was observed in 2006. In a study of laboratory foraging habits of largemouth bass, Schramm and Zale (1985) also observed a preference for small blue tilapia over small bluegill, which may partially explain the relatively low FO values for bluegill when compared to FO for threadfin shad and blue tilapia.

While reduced water levels are commonly associated with increased predation and cannibalism resulting from the concentration of fish and reduction of refugia (Carlander 1977; Conley et al. 2004; Havens et al. 2005; Hoyer and Canfield 2001; Sammons et al. 1999), the absence of age-0 largemouth bass from stomach contents suggests that cannibalism did not occur during our sampling at La Juventud. However, age-0 largemouth bass could possibly have been included among the partially digested unidentifiable fishes in largemouth bass stomach contents, as could any of the other fishes that were able to be identified.

Aside from fishes, aquatic insects were also utilized frequently, especially by smaller sub-stock and stock-length individuals. Crayfish were observed only in the diets of stock-length largemouth bass, and along with arachnids, were consumed infrequently.

Channel catfish

The percentage of empty stomachs among channel catfish was lowest in 2007. The resurgence of digestive activity within freezer preserved stomachs during a weekend power outage may have elevated the percentage of empty stomachs in 2006; regurgitation and post-capture digestion associated with overnight sampling periods (Bowen 1996) may have elevated the percentage of empty stomachs in 2008 gill-net collections. There was no apparent seasonal trend (summer to fall) in empty stomachs of channel catfish.

The diet of channel catfish at La Juventud consisted of a wide variety of food items and was consistent with their omnivorous feeding habits reported in the literature (Carlander 1977; Hubert 1999; Wellborn 1988). Channel catfish at La Juventud frequently consumed aquatic insects, fishes, terrestrial insects, other vertebrate food items, and plant material. Studies show that individuals of about 11 to 30-cm TL feed on larger aquatic insects, and their diet diversity is augmented by terrestrial insects, crayfish, mussels, small fish, and plant material; individuals greater than 30-cm-TL begin to incorporate fish into their diets while remaining heavily dependent on invertebrates and other available food types (Hubert 1999). The presence of two food items (common carp and huisache legumes) in stomach contents of channel catfish collected at La Juventud suggest opportunistic use of available food items (Edds et al. 2002) and is also consistent with the generalist nature of channel catfish feeding habits (Hubert 1999).

Channel catfish frequently utilized fish, as well as a wide variety of other food items. Thus, catfish may possibly be free from the growth limitations that constrain species with narrower diets. Hubert (1999) noted that where fish are not common in the diet, growth may be relatively slow.

Condition

Largemouth bass

Relative weight is intended to estimate the short-term physiological condition of a fish and is primarily influenced by food availability and seasonal changes in gonadal development (Pope and Willis 1996). Values below 95 are associated with inadequate prey availability, and the severity of the deficiency increases with the distance from this benchmark (Anderson and Neumann 1996; Pope and Kruse 2007).

Except for preferred (380 – 509-mm TL) largemouth bass in 2007, mean Wr for fish collected by electrofishing and gill-netting (2006, 2007, and 2008) were slightly to moderately below the optimal range and suggest inadequate prey availability in La Juventud. Alternatively, these low Wr values could represent post-spawning status of mature largemouth bass (≥ stock size). For spring spawners, fish condition is usually highest just before spawning, then declines immediately after spawning, and increases through the summer and into the fall (Pope and Willis 1996). In sub-tropical

Northeastern Mexico, spring and fall temperatures are relatively similar and observed low values of Wr may indicate that spawning had resumed in the fall as water temperatures cooled down from hot summer conditions. High age-0 CPUE values in November electrofishing collections and November water temperature readings within the range of largemouth bass spawning (15-24°C) further suggest that a second spawning season occurred at La Juventud. Positive correlations between Wr and growth have also been reported for largemouth bass (Wedge and Anderson 1978) and low Wr of largemouth bass in La Juventud are consistent with the pattern of slower growth of older individuals (see chapter I).

Channel catfish

Although mean Wr for channel catfish was highest for sub-stock- and quality-length individuals in 2006, these Wr values were well below the optimal range. Relative weight has proven useful as an indicator of food availability and values below 95 are associated with inadequate prey availability (Anderson and Neumann 1996; Pope and Kruse 2007). Only the single channel catfishes of preferred- and memorable-lengths in La Juventud had Wr values above the optimal range.

Standard weight (Ws) equations are computed using summaries of length and weight from across the U.S.A. (Brown et al. 1995). Therefore, the growth form modeled by species-specific standard-weight equations may not apply to Mexican regions that are outside of the geographic range of fish used to create Ws equations, and if so, then Wr results for La Juventud may not be comparable to those across the U.S.A.

Prey Availability

The availability of prey is a major factor affecting growth of predatory fishes and is a function of not only prey abundance, but also the size and body conformation of the prey relative to mouth-size and shape dimensions of the predator (Lawrence 1958; Shelton et al. 1979). Seine CPUE and percent frequency of occurrence (FO) values indicated that threadfin shad were abundant in La Juventud reservoir and a common prey species of largemouth bass across all length categories. Threadfin shad however, are short lived and generally do not exceed 175-200-mm TL (Higginbotham 1988), and thus of limited suitability as prey for large piscivores (Davis and Lock 1997; Shelton et al. 1979). Carlander (1977) also suggested that growth of largemouth bass is commonly related to the availability of adequate-size forage.

The majority of bluegill and blue tilapia captured by electrofishing, gill-netting, and seining were either smaller than 140-mm TL or larger than 250-mm TL. Largemouth bass swallow whole prey, and the maximum size of prey they can consume is constrained by gape width, which increases as largemouth bass grow (Gill 2003). Young piscivorous largemouth bass may benefit from the relatively abundant small, blue tilapia observed in seine and electrofishing samples. However, Schramm and Zale (1985) noted that the blue tilapia as prey may be limited by their rapid growth rates and morphological unavailability. Therefore, the suitability of blue tilapia greater than 250-mm TL as forage for large piscivores in La Juventud, likely is limited by such morphological unavailability. Similar results were observed in a study of clupeid prey availability to primary piscivores in Smith Mountain Lake, Virginia; rapid growth rates of gizzard shad made them morphologically invulnerable to young predators (Cyterski and Ney 2005). Given that the majority of largemouth bass collected in La Juventud were smaller than 340-mm TL, the tilapia size structures may reflect a population in which younger-smaller individuals are effectively cropped by predation resulting in rapid growth to sizes less vulnerable to predation.

In small impoundments, bluegill are particularly important because their reproduction throughout the warm months furnishes a continual supply of variously-sized forage to predatory fishes (Davis and Lock 1997). For example, in Alabama ponds the growth of young largemouth bass increased whenever bluegill fry were present (Carlander 1977; Elrod 1971). In La Juventud, bluegill size structure and low bluegill PSD values (3) indicated that few fish exceeded 150-mm (Gablehouse 1984a; Gablehouse 1984b; Guy and Willis 1990; Willis et al. 1993). Studies indicate that an inverse relationship between predator and prey size structures , driven by predation dynamics, is likely to be reflected in largemouth bass and bluegill PSD values (Willis et al. 1993). However, moderately low largemouth bass PSD (see chapter I) and very low bluegill PSD estimated for La Juventud, do not match these predictions. Schramm and Zale (1985) noted that small blue tilapias were preferred over bluegill of similar size, and that the availability of blue tilapia as forage could potentially serve as a buffer against largemouth bass predation on bluegill, consequently affecting predatory-prey dynamics, and ultimately resulting in reduced and inadequate predation on bluegill, overcrowding, and slow growth to longer lengths (Gablehouse 1984a; Schramm and Zale 1985). Nevertheless, at La Juventud, drought prone conditions favoring unstable recruitment, and evidence suggesting selective removal of larger fish by anglers (see chapter I), require that caution be used when interpreting predator-prey dynamics from stock-density indices (Willis et al. 1993).

Seine haul CPUE results and bluegill and blue tilapia size structures in La Juventud suggested that relatively few larger-size individuals of small-bodied prey (threadfin shad and bluegill) and few vulnerable-size individuals of larger-bodied prey may be available for the continued development of larger (300 – 380-mm TL) predators. A shortage of suitable-size prey would be consistent with shorter mean values of length-at-age for older largemouth bass (see chapter I), which suggested rapid growth during early years and stunting of fish older than age-3 (see chapter I). Miranda and Bettoli (2007) also noted that limited food can directly influence mortality of early life stages of predatory fishes, and indirectly influence mortality of later life stages by reducing growth and lengthening the time predators spend searching for food. Furthermore, Wr results for both largemouth bass and channel catfish suggest inadequate prey availability. In addition, for channel catfish and largemouth bass, the discrepancies between lower Wr of smaller (sub-stock to quality size) as compared to higher Wr of larger (preferred and memorable size) fish may be explained by the broader variety of larger food items, such as common carp and other vertebrates, that may be more available (numerically and morphologically) than blue tilapia, bluegill, or threadfin shad.

CHAPTER IV

FISH ASSEMBLAGE

INTRODUCTION

Exploratory analysis of the shallow-water shoreline fish assemblage structure was conducted to infer the biotic-abiotic relationships among fish species, water quality, and habitat.

METHODS

Multivariate Analysis

Multivariate detrended correspondence (DCA) and redundancy analyses (RDA) were used to summarize variation in the fish assemblages collected by seining, electrofishing, and gill netting, and infer relationships among environmental parameters and assemblage structure at La Juventud. All multivariate statistical analyses were performed with CANOCO version 4.5; relative abundance (CPUE) of species were log-transformed to induce symmetry if abundance data ranged more than three-fold in magnitude within a dataset. Species were further differentiated into length categories to reflect the ontogenetic differences in ecological characteristics such as trophic interactions and habitat use (Gelwick and Matthews 1996). A preliminary DCA was performed to determine whether the data followed either a unimodal or linear trend along multi-species axes scaled in standard deviations (SD). The linear trend is most common when the species gradients are short (<3 SD), and the unimodal trend when the gradients are long (>4 SD) (Ter Braak and Smilauer 2002). Because no axis was > 2 SD in length for any of the three datasets (Table 11), a redundancy analysis (RDA) for linear trends was used for the remaining analyses. RDA is a multivariate regression method by which the relationships between multiple response (dependent) and environmental (explanatory, independent) variables are determined by constraining the axes to linear combinations of explanatory variables (Ter Braak and Smilauer 2002). Explanatory environmental variables for ordination of our seine haul data were water quality (temperature, dissolved oxygen concentration, turbidity, and conductivity), sample year (2007, 2008), and substrate type (clay, clay with imbedded rock, rock). Moreover, significant variables determined to be highly colinear with many other variables (i.e., those having variance inflation values > 5.0) were removed from the final model, but included as supplementary variables (i.e. are passive variables based on their post-hoc correlation with explanatory axes, and thus do not influence the ordination). Supplemental environmental variables were secondarily plotted on the ordination diagram so that their relation to the species, other explanatory variables, and samples could be visualized (Ter Braak and Smilauer 2002). Explanatory environmental variables for ordination of our seine haul data were water quality (temperature, dissolved oxygen concentration, turbidity, and conductivity), sample year (2007, 2008), and substrate type (clay, clay with imbedded rock, rock. Moreover, significant variables determined to be highly correlated with many other variables (i.e., those having variance inflation values > 5.0) were removed from the final model, but included as supplementary variables (i.e. are passive variables based on their post-hoc correlation with explanatory axes, and thus do not influence the ordination) that were secondarily plotted on the ordination diagram so that their relation to the species, explanatory variables and samples could be visualized (Ter Braak and Smilauer 2002). The correlation coefficients for explanatory variables and canonical axes were interpreted as significant if their t-value was > |2.1|. Monte Carlo permutations (499 permutations) were also performed with CANOCO; the test statistic for non-permuted data was compared to the test statistic determined from random permutation of the species data, and the F-ratio was used to test (P-value ≤ 0.5) the null hypothesis that the variation in distribution of species data among samples was unrelated to the variation in explanatory data (Ter Braak and Smilauer 2002).

RESULTS

Multivariate Fish Data

The results of the DCA (SD) across the first axis for each sampling method ranged from 1.662 to 1.757 (Table 11), indicating short gradients across which relative abundances of species were the primary differences among samples, rather than change in species composition. The first two RDA axes explained 51.9 % of the variation in the species data itself, and 84.7% of the variation in the species-environment relationship (Table 12). Although, neither the first canonical axis, nor all canonical axes combined, explained a statistically significant amount of the species data (respectively, F-ratio = 4.590, p = 0.080; F-ratio = 1.581, p-value = 0.1100), the species-environment trends show commonly observed ecological relationships, and therefore trends in these will be described. Sample sites and species codes are defined in Table 13. Environmental variables indicate that Axis 1 of the RDA is a gradient (left to right in Figure 27) of samples at sites associated with increasing depth, higher dissolved oxygen and presence of primarily rock substrate (t-values = |5.34|, |4.31|, and |4.80| respectively), whereas axis 2 is a gradient (top to bottom in Figure 27) of samples at sites associated with lower specific conductivity values (t-value = |2.22|). Year 2007 was included as a supplementary categorical variable, and was correlated (t-value = |2.49|) with the first axis, whereas the two other supplementary variables (temperature and Year 2008) were not strongly correlated (all t-values < |2.1|) with either axis.

Table 11. Seine haul detrended correspondence analyses gradient lengths (SD). Lengths of gradients (SD) for detrended correspondence analyses on relative fish abundance and environmental variables from seine hauls, electrofishing, and gill net samples collected from the littoral and limnetic zones at La Juventud reservoir in Nuevo Leon, Mexico.

Axes	1	2	3	4
Seine				
Detrended Correspondence Analysis				
Lengths of gradients (SD)	1.672	1.490	0.745	0.607

Table 12. Seine haul redundancy analysis (RDA). Summary statistics for redundancy analyses on datasets for relative abundance of fish, and values for environmental variables sampled by seining and electrofishing (littoral habitats), and gill netting (limnetic zones) in La Juventud reservoir, Nuevo Leon, Mexico.

Axes	1	2	3	4	Total Variance
Seine					
Redundancy Analysis					
Eigenvalues	0.433	0.086	0.051	0.030	1.00
Species-environment correlation	0.962	0.828	0.915	0.541	
Cumulative percentage variance:					
of species data	43.3	51.9	57.0	60.0	
of species-environment relation	70.8	84.7	93.0	97.9	
Sum of all eigenvalues					1.00
Sum of all canonical eigenvalues					0.613

Table. 13 Sample site and species codes with definitions.

Seine Haul Sample Site Codes	Definition
Ent07	Entrance 2007
CkU07	Creek Upper 2007
Road07	Road 2007
Dam08	Dam 2008
CkMU08	Creek Mouth Upper 2008
CkMD08	Creek Mouth Lower 2008
Ck100m08	Creek 100 Meters Upper 2008
Ckm15m08	Creek 15 Meter Upper 2008
PkNSh08	Park Northern Shore 2008
PkSWCv08	Park Southwestern Cove 2008
PkSWSh08	Park Southwestern Shore 2008
PumpA08	Pump A 2008
PumpB08	Pump B 2008
Species Codes	**Definition**
LMB+150	Largemouth Bass > 150-mm TL
LMB-150	Largemouth Bass < 150-mm TL
BG+100	Bluegill > 100-mm TL
BG80-100	Bluegill 80-100-mm TL
BG-80	Bluegill < 80-mm TL
TA+80	Blue Tilapia > 80-mm TL
TA-80	Blue Tilapia < 80-mm TL
TA-25	Blue Tilapia < 25-mm TL
MT+80	Mexican Tetra > 80-mm TL
MT-80	Mexican Tetra < 80-mm TL
TS-60	Threadfin Shad < 60-mm TL
MF	Mosquito Fish

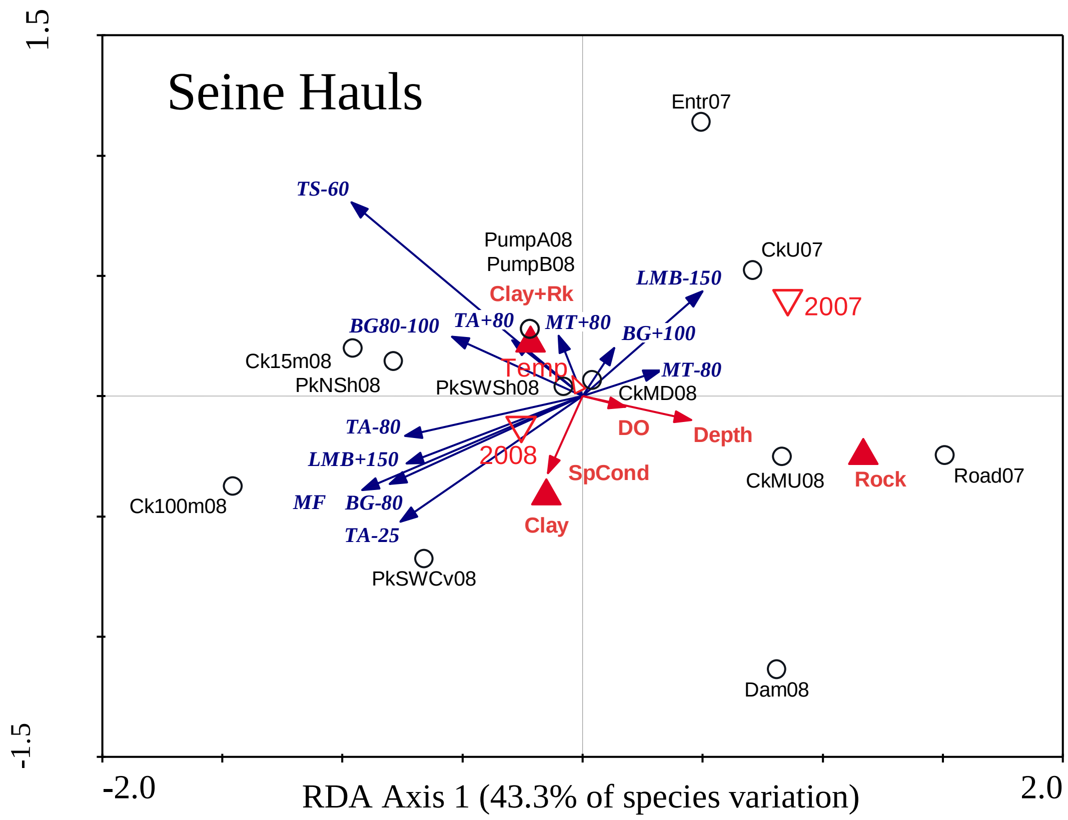

Figure 27. Seine haul ordination diagram. Ordination triplot showing the relationship between relative fish abundance (blue arrows labeled as species), environmental variables (red arrows are continuous variables, red filled triangles are nominal variables, and open triangles are supplemental nominal variables), and samples (open circles) collected by seine haul at La Juventud, Nuevo Leon, Mexico in June 2007 and 2008.

Largemouth bass > 150-mm TL, bluegill < 80-mm TL, tilapia < 80-mm TL and smaller blue tilapia < 25-mm TL, and western mosquitofish were negatively correlated with axes 1 and 2 (lower left quadrant in Figure 27) and positively correlated with specific conductivity and predominantly clay substrate. These species were mostly associated with seine hauls collected upstream in Saliditо Creek, and near the park along the western shoreline of the main reservoir in 2008. Largemouth bass < 150-mm TL were positively associated with the furthermost upstream seine hauls in Salidito Creek in 2007, but in 2008 were negatively associated with seine hauls taken upstream in Salidito Creek and in the shallow southwest cove near the park (Figure 27).

Threadfin shad < 60-mm TL and bluegill 80-100 mm TL were negatively correlated with axis 1 and positively correlated with axis 2 (upper left quadrant in Figure 26) and were associated with seine hauls taken throughout the shoreline of the main reservoir and tributary arm of the reservoir on the southeastern shore, western shore, and upstream in Salidito Creek in 2008. They were also characterized by a negative correlation with rock substrates and depth, and a positive correlation with clay substrates with imbedded rocks. Furthermore, the strength of the threadfin shad abundance gradient represented by the longer species arrow in the triplot is greatest among all species and is equally associated with both axes (upper left quadrant in Figure 27).

DISCUSSION

Multivariate Fish Data

Low DCA sample scores for all sampling methods indicated that assemblages were somewhat homogenous and only differed in relative abundances among species rather than changes in presence or absence of particular species groups (Verdonschot and Ter Braak 1994). The first two RDA axes for the seining dataset containing greatest number of species-size groups, and accounted for more than 50% of the variation in their distribution among samples (Table 12). The ecological patterns for this dataset were not statistically significant, but they are consistent with those commonly reported for reservoirs and therefore are discussed further.

Increasing DO was associated with near shore seine hauls collected in shallow water over rock substrates, where penetrating light conditions and warm temperatures may favor the growth of algae and production of oxygen. In addition, fewer species groups were associated with greater occurrence of rock substrates and deeper waters. Rocky substrate also may facilitate refuge for fish from capture in seine hauls, which are inefficient in such habitats, particularly in deeper water (Lyons 1986).

Interactions between habitat structure and limnological patterns influence the structure of reservoir fish assemblages (Gido et al. 2002; Gido and Matthews 2000; Lieneshch and Matthews 2000) and similar interactions appear to be present in La Juventud. Young-of-year largemouth bass < 150-mm TL collected by seining were associated with the furthermost upstream sample sites of Salidito Creek in 2007 (Figure 26). Largemouth bass > 150-mm TL, bluegill < 80-mm TL, tilapia < 80-mm TL, tilapia

< 25 -mm TL, and western mosquitofish also were among those associated with sample sites upstream in Saldito Creek. Although habitat type was not quantified at sample sites, habitat complexity appeared to be greater (personal observation) in the upstream reach of Salidito creek where a mixture of rooted trees, undercut banks, aquatic macrophytes, and brush are located over clay and clay with imbedded rock substrates. Such structural complexity provides refuge for prey species and juvenile fish from predators (Hoyer and Canfield 2001; Sass et al. 2006).

Runoff of nutrients and organic matter into the stream may account for the positive correlation between specific conductivity and fishes in upstream samples. Total suspended solids and nutrient concentrations often are greatest in the tributary arms of reservoirs (Kennedy and Walker 1990) and UANL staff have indicated that a hog farm exists only a few kilometers upstream on Salidito Creek (personal communication, Sergio Rodriguez and Luis Lozano, UANL Biologists). Moreover, the apparent correlation of specific conductivity with fish species in RDA diagrams can possibly be attributed to the relatively higher conductivity values recorded throughout the reservoir in June 2008 (Figures 26). Conductivity values often increase as a result of reduction in reservoir volume and subsequent increase in concentration of dissolved nutrients and ions during drought conditions (Bouvy et al. 2003).

Threadfin shad < 60-mm TL and bluegill 80 - 100-mm TL were associated with seine hauls taken at a variety of sample sites throughout the reservoir and the main tributary arm (Salidito Creek), and were positively correlated with clay imbedded with rocks (Figure 26). Threadfin shad use diverse habitat types including lentic, lotic, and estuarine systems (Miller et al. 2005) and had the highest RDA species tolerance score (an index of the breadth of species distribution among samples) among seine haul samples.

The fluctuating nature of reservoir water levels and its effect on the reproductive success of fishes may cause assemblages of nest spawning species to vary (Gido and Matthews 2000; Maceina and Pereira 2007; Sammons et al. 1999). For example, La Juventud reservoir experienced an extended drought from December 2007 to July 2008 during which water level declined drastically and may have decreased the amount of preferred upper-reservoir spawning substrate available to nest spawners such as largemouth bass. Furthermore, critical spawning and physical habitat along the shoreline of La Juventud may no longer have been inundated by mid-June when seine sampling took place and may explain the negative correlation between clay substrates, 2008 seine haul samples, and young-of-year largemouth bass in the seine RDA diagram (Figure 26).

CHAPTER V

CONCLUSION

SUMMARY AND RECOMMENDATIONS

The near absence of largemouth bass ≥ 340-mm TL and ≥ age-3 may indicate either slower growth to larger sizes or higher mortality rates associated with the selective removal by angling of larger (generally older) fish. Estimates of PSD at the lower extreme of the range (0 – 100) have also been correlated with slow growth, and high mortality rates. Extended spawning efforts at lower sub-tropical and tropical latitudes have also been implicated in the acceleration of mortality rates of reproductively mature largemouth bass.

The total mortality rate estimated for largemouth bass collected by electrofishing in La Juventud was slightly higher as compared to a range of values reported for populations throughout the U.S.A., and was consistent with the interpretations of population length-frequency and age-frequency distributions.

Largemouth bass at La Juventud grew fast during the first year of life and attained a larger size by age-1 as compared to populations from the Southeastern U.S.A. The growth of younger and smaller largemouth bass may benefit from the presence of a seemingly abundant (as indicated by seine haul CPUE values) multi-species forage base of small fish. Moreover, threadfin shad, blue tilapia, and bluegill spawning can begin shortly after that of largemouth bass and may provide an excellent forage base throughout the majority of the first growing season. An early onset of spawning and extended length of the growing season at lower sub-tropical latitudes where temperatures fluctuate little between seasons can also provide another possible explanation for relatively longer fish at age-1.

Although few older fish were collected, the growth of largemouth bass older than age-3 appeared stagnant and may indicate a stunted population. Estimates of Wr suggested that prey availability may have been inadequate in 2006, 2007, and 2008; analyses of prey species CPUE and size structures suggested a scarcity of larger (threadfin shad and bluegill) and morphologically-vulnerable (blue tilapia) prey available to large predators at La Juventud. Protracted spawning periods associated with nearly year-round warm water temperatures in sub-tropical and tropical regions may also divert energy away from somatic growth of older reproductively mature individuals. If similar climate and growth conditions exist in sub-tropical Northeastern Mexico then the feasibility of trophy and tournament fishing in the region may be limited without specific management intervention.

Seining during summer may be ineffective for assessment of largemouth bass reproductive success due to the potential for spawning relatively early in the year and suspected additional spawning events in fall. Undesirable interactions (competition for forage and spawning sites, and egg predation) with bluegill and blue tilapia, and fluctuating water levels associated with a variable precipitation regime and drought prone climate, also may periodically reduce the spawning success of largemouth bass in La Juventud.

The diet of largemouth bass at La Juventud consisted mostly of aquatic insects, crayfishes, and fishes. The pattern of decreased consumption of aquatic insects and increased consumption of fishes and crayfish with increasing length is consistent with documented ontogenetic trophic shifts for this species. Of the ingested fishes that were identifiable, threadfin shad were most frequently consumed by largemouth bass throughout all years.

Potentially variable reproductive success, fast growth to quality size (300 – 379 mm TL), and high mortality rates support the use of minimum length limits between 300 and 380-mm TL. A minimum-length limit closer to 300-mm TL should provide anglers with a higher total yield (kg) and number harvested, but mean size and mean weight of fish harvested would be smaller than with a minimum-length limit closer to 380-mm TL. Thus, a tradeoff exists between quantity (number of fish harvested) and quality (size of fish harvested).

Effective sampling of channel catfish in small impoundments is often difficult to achieve and day-time gill net collections in 2006 and 2007 may have under sampled channel catfish, which are generally more active at night. As a result, gill net catches were low and variable; thus, interpretation of length, age, and weight data were constrained by small sample size. Only two channel catfish greater than preferred-length (610 mm TL) were captured across all samples, which may indicate high mortality rates due to the selective removal of larger fish by anglers; however, interval mortality rates (A) estimated from pooled catch-at-age data collected by gill netting across years 2006-2008 were moderately low (24%) and survival (76%) was within the range reported in other North American systems. Small sample sizes may explain conflicting interpretations of size structure and mortality rate estimates.

Channel catfish mean length-at-age values were similar to the mean of means for length-at-age values of fish in Texas, and larger than the mean values from several regions in the Southern U.S.A. Channel catfish grow and reproduce best in warm water environments, thus sub-tropical conditions in Northeastern Mexico may provide one explanation for these results.

Variable stocking rates of fingerling channel catfish, removal of a significant proportion of natural reproduction due to predation by largemouth bass and over-wintering double-crested cormorants, and fluctuating water levels associated with variable precipitation and a drought-prone climate all have the potential to adversely influence the recruitment success of channel catfish at La Juventud.

Channel catfish frequently utilized fish, as well as a wide variety of other food items, which is consistent with the omnivorous feeding habits of this species. Regardless, Wr values of smaller length categories were well below the optimal range and may suggest inadequate prey availability. Analysis of size structures and CPUE of major forage species in La Juventud suggested limited availability of larger prey items suitable for larger individuals of both largemouth bass and channel catfish. Minimum-length limits > 350-mm TL may be necessary to insure that a significant proportion of the channel catfish can become sexually mature and spawn before becoming vulnerable to harvest.

Species collected by seine hauls were commonly associated with the furthermost upstream sample sites of Saldito Creek where habitat complexity and refuge appeared to be greatest. No fish were associated with samples collected in deeper waters over rocky substrates where seine hauls are inefficient at capturing fish. Threadfin shad were associated with seine hauls taken at a variety of shoreline sites throughout the reservoir. Runoff of nutrients and organic matter into Salidito Creek may account for the positive correlation between fishes in upstream samples and specific conductivity, turbidity, and total dissolved solids. Furthermore, lower water levels in 2008 and subsequent concentration of nutrients, may account for the positive correlation between 2008 seine collections and specific conductivity.

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